TRW 35515-6002-RU-00

PEP SOLAR ARRAY DEFINITION STUDY

FINAL PROGRAMMATIC REPORT

30 OCTOBER 1979

NAS 9-15870

(NASA-CR-160398) PEP SOLAR ARRAY DEFINITION STUDY Final Programmatic Report (TRW Defense and Space Systems Group) 82 p HC A05/MF A01 CSCL 10A N80-13622 Unclas G3/44 46256

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DEFENSE AND SPACE SYSTEMS GROUP

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Prepared For

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Lyndon B. Johnson Space Center
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By

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FOREWORD

This document is submitted in accordance with Article XI of Contract NAS 9-15870 and represents the deliverable under Line Item 3 (MA183TFB) of the Data Requirements List.

The data presented here completes the activities of Tasks 2, 3 and 4 under the Power Extension Package (PEP) Solar Array Definition Study. Included are Development and Manufacturing Facilities Plans and Cost, Schedule and Risk Assessments for the design, fabrication, test and delivery of PEP Solar Arrays.

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1.0 INTRODUCTION

The Power Extension Package (PEP) is a solar array system that will be used on the Space Transportation System (STS) to agument the power of the Orbiter vehicle and to extend the time the vehicle may stay in orbit. This additional power and duration is only required on specific missions, hence the PEP system is designed for easy installation and removal from the cargo bay of the Orbiter vehicle. The system consists of two major assemblies; the power regulation and control assembly, and the array deployment assembly. In addition the deployment requires the use of displays and controls, a remote manipulator system (RMS), and some additional minor amounts of hardware to interface with the Orbiter structural and electrical subsystems. The configurations in the deployed and stowed modes are illustrated in Figures 1 and 2 respectively.

The PEP program as structured during the definition phase consists of a system contractor and solar array contractor, with the latter having responsibility for providing a conceptual design of the solar array, a development plan, a manufacturing facility plan and a cost-schedule risk assessment. The TRW PEP solar array design is presented in Reference 1. The programmatic aspects of the design covering the development plan, the manufacturing facility plan and the estimated costs and risks are presented in this document.

The baseline configuration of the solar array is briefly reviewed in Section 3.0. The program plan including schedules, verification activities and mission support are presented in Section 4. The manufacturing facilities plan covering solar module laydowns, fabrication of mechanical parts and

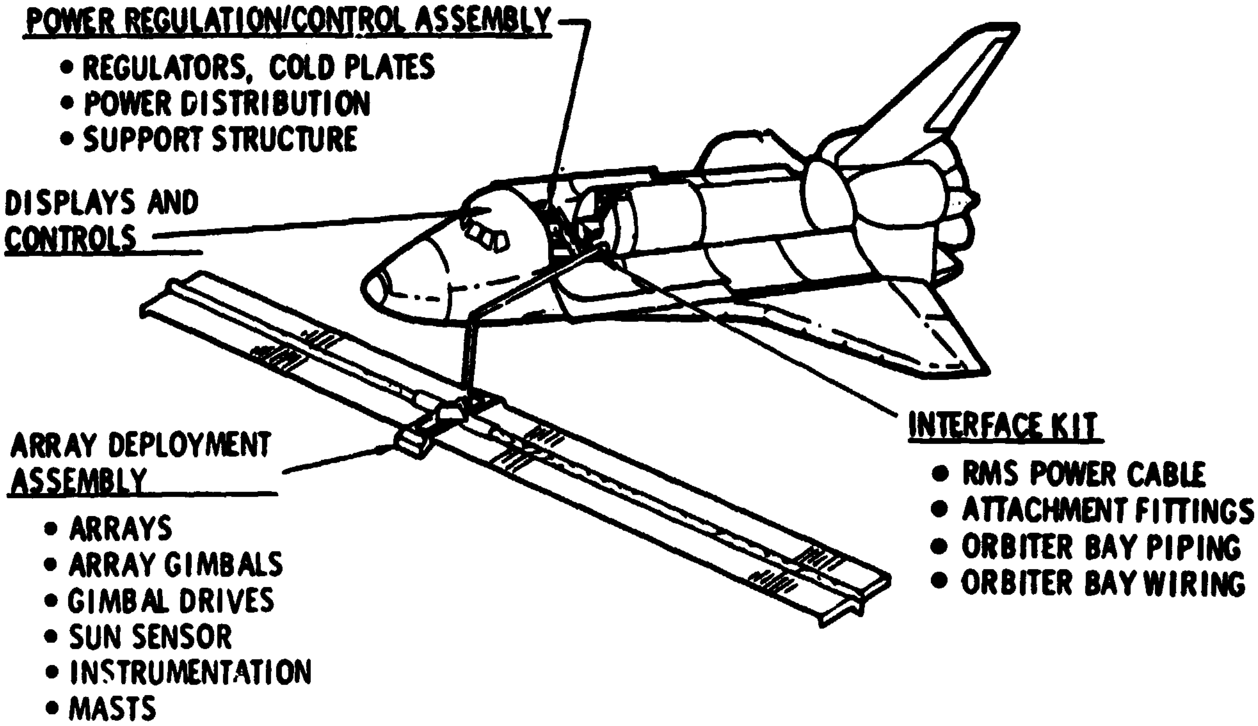


Figure 1. Power Extension Package - Deployed

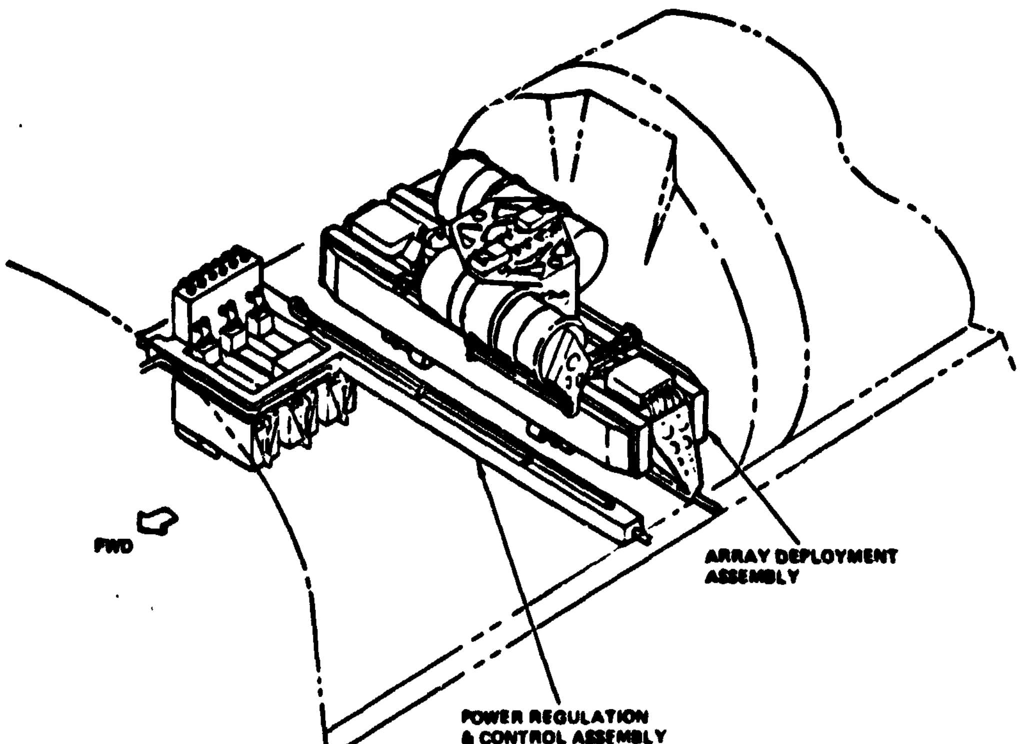


Figure 2. Power Extension Package - Stowed

facilities layouts for solar array assembly are presented in Section 5.0 The cost/risk assessment is summarized in Section 6.0.

2.0 PURPOSE AND SCOPE

2.1 Purpose

The purpose of this document is to summarize the programmatic planning activities and estimated costs and risks associated with the development and delivery of qualified solar arrays for the PEP System.

2.2 Scope

The programmatic activities reported in this document are the program plan and manufacturing facilities plan to design, develop, manufacture, test and maintain the solar arrays for the PEP system. These plans are based on overall program milestones as defined by the PEP System Study Contractor (Reference 2) and for the solar array elements as defined in Section 3.0.

The specific programmatic tasks were:

1) Definition of activities to develop, manufacture, test and perform pre- and post mission maintenance operations for the solar array subsystem.

2) Definition of manufacturing tasks, manufacturing flow, sustaining engineering and tooling, material, assembly, line inspection, checkout and supplier activities related to the production of flight hardware for the PEP solar arrays. Identify present on-line capability and near term adaptions commensurate with providing the most cost

effective approach to manufacturing the arrays.

3) Definition of ROM costs to develop and manufacture flight sets of PEP solar array components, and schedule/risk assessments associated with the hardware baseline PEP schedule.

3.0 DESIGN DESCRIPTION

The planning activity described in the subsequent sections of this document are based on specific solar array configurations formulated during the conceptual design phase of the study. The principal features of the baseline design are described in this section. An alternate design using a larger solar cell has also been evaluated and the impact on the baseline design is defined. The PEP solar array system consists of two solar array wings. Since the wings are identical the descriptions that follow will be for one wing assembly only.

3.1 Baseline Design

The PEP solar array is designed for operation in low earth orbits (100 to 600 N mi.) at inclinations of 28.5 to 104 degrees. It is required to deliver 32.8 Kw of unregulated power at beginning of life at a voltage of 100 to 125 volts. The array must be compactly stowed within the orbiter vehicle during boost and reentry and must deploy and retract while in orbit. To meet these fundamental requirements the solar array is designed as a group of assemblies. The basic unit of assembly of a solar array wing is solar cell panel. The panels are hinged together to form a blanket assembly. The blanket housing assembly contains and protects the blanket during boost and reentry, and then provides guidance and tension of the blanket during deployment and normal operation. The mast/canister assembly is the mechanism that is used to deploy and retract the blankets from the containers after the array deployment assembly is removed from the Orbiter Cargo bay with the RMS. The mast/canister assembly was not included in the current design phase as a part of the solar array, however, because of the large impact it has on the solar array design, a brief description is included in the following sections for completeness.

3.1.1 Blanket Assembly

The baseline design of the PEP solar array blanket is illustrated in Figure 3. The blanket is made up of 102 solar cell panels. It has a leader at the forward and aft ends and is 1456 inches long. The forward

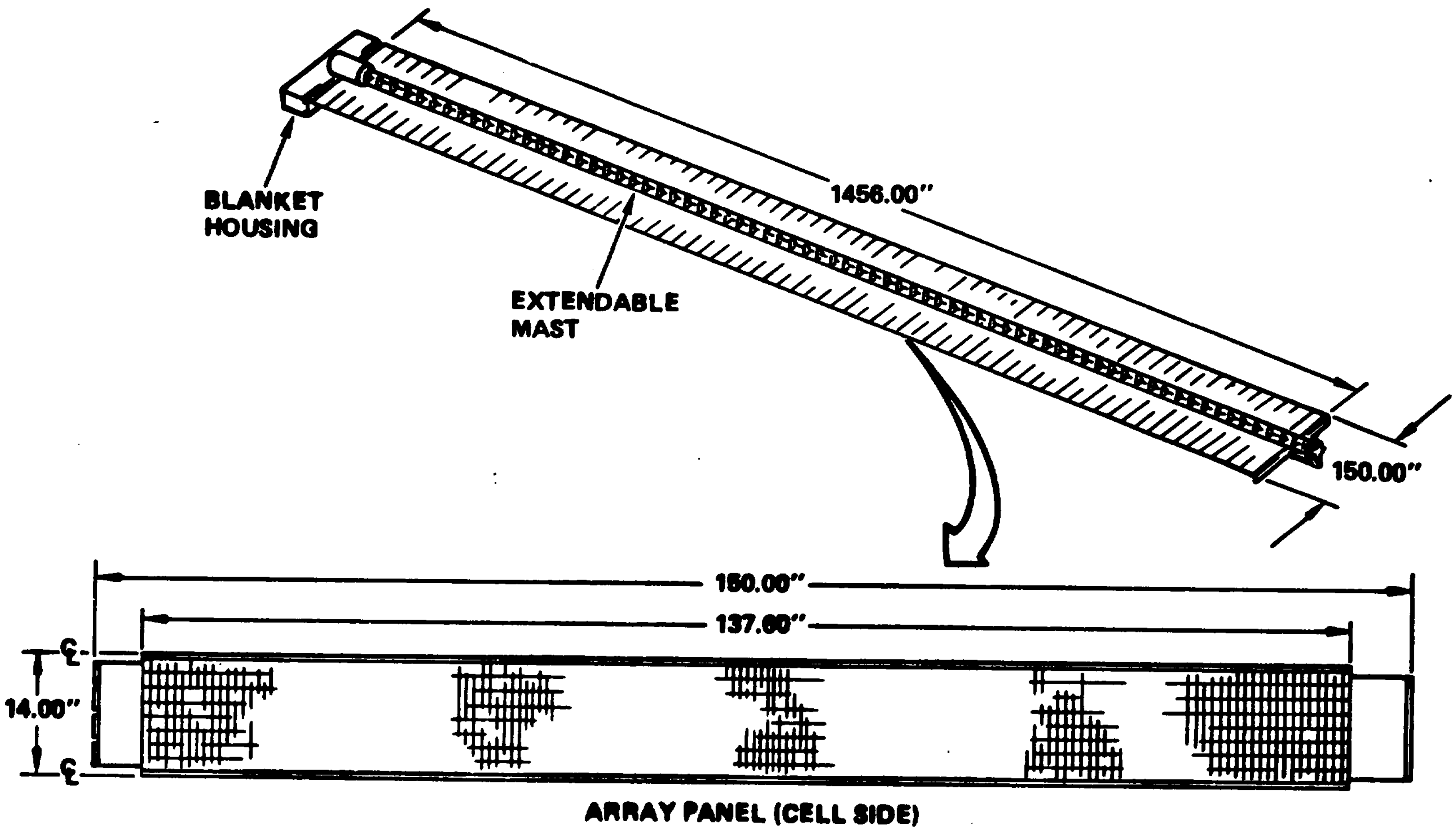


Figure 3. Solar Cell Blanket Configuration

leader attaches to a spreader bar which is connected to the deployment mast tip through two linkages. The bottom leader attaches to the blanket housing base by a set of negator springs which maintains uniform tension of the blanket in the deployed configuration.

The major subassembly unit is the solar cell panel which is also illustrated in Figure 3. The individual panels are 150 by 14 inches and are composed of two plies of one mil Kapton sheets with integral formed ribs in each of the plies. The ribs extend over the solar cell area of the panels which is the 137.6 by 14 inch dimensions. A film adhesive is used to bond the two plies together. The outer six inches of one ply has space allocated for harness runs at each end of the panel. A ground handling loop is also provided.

The solar cells selected for the baseline design are P^+, 14% efficient, silicon cells. Each cell is 2.22 x 3.96 centimeters in size and 8 mils in thickness. The cells have polished front surface with a back side reflector and a back side field. Conventional soldered contacts are used. The cover glass is 6 mil microsheet of a size slightly larger than the solar cell that it is bonded to. U-shaped, silver plated invar interconnects are soldered to the cells to provide long fatigue life connections between cells.

The solar cells are arranged on each panel in 8 strings of 150 cells per string to provide approximately 63 volts and 165 watts per panel. The cells are oriented with the 2.22 cm dimension in the series direction and the cell strings are arranged along the long dimension (137.6 inch) of the panel. Approximately every eleven cells there is a parallel interconnection between the eight strings of cells. At each end of the panel is a metallic terminator strip which collects the power and provides an interconnection to the power harness. The ribs on the solar cell side of each panel run between the cell strings along the length of the panel. The ribs on the opposite (shade) side of each panel run the width of the panel and are spaced every other cell in the series direction.

The individual solar panels are connected together by hinges which are constructed in such a manner as to provide a positive force during the refolding operation. Each hinge is composed of two plies

of 3 mil Kapton separated by a polyurethane spacer. An inner ply of one mil Kapton is used to provide a tension tie across the hinge in the deployed configuration. The hinges are pre assembled by bonding the pieces together and are then bonded to adjacent panels to complete the interconnection for the blanket assembly.

The blanket has two power harnesses that are bonded to the outer ends of each panel. A harness is a single flat layer of stranded conductors. Each conductor is composed of copper coated aluminum wires that very from 18 to 20 AWG sizes depending on losses and length in the harness. The conductors are bonded between two sheets of Kapton, one of which is corrugated to provide spacing insulation and the other flat to complete the insulation properties and to provide a mating surface to the panels. The harness is pre-formed with prayer tab configurations at the hinges and then bonded to the panels. The individual harness wires are connected to a panel terminator strip with a connector ribbon. By alternating the polarity in adjacent wings, it is possible to minimize magnetic torques on the wing. Extra conductors are included in the harness for instrumentation. Each harness terminates at a junction box in the wing container.

3.1.2 Blanket Housing Assembly

The blanket housing assembly protects the solar array blanket during launch and re-entry. It consists of the container, the lid, the latch and preload mechanism, the blanket tensioning mechanism and the guide wire system. The assembly is presented in Figure 4 with the lid closed in one view and with the lid opened in the other. The container structure is currently baselined as aluminum construction but if weight problems develop composite materials will be substituted to the extent possible. The floor and lid of the container are honeycomb with the ends and walls of thin sheet stock. Fittings are provided at four locations on the housing to serve the dual functions of lid latching/hinge points and as attachment fittings to the system contractor's core structure.

The lid is hinged to the housing at two locations on one side, and latched closed for preload at two locations on the opposite side. The hinges are designed to permit the lid to both translate and

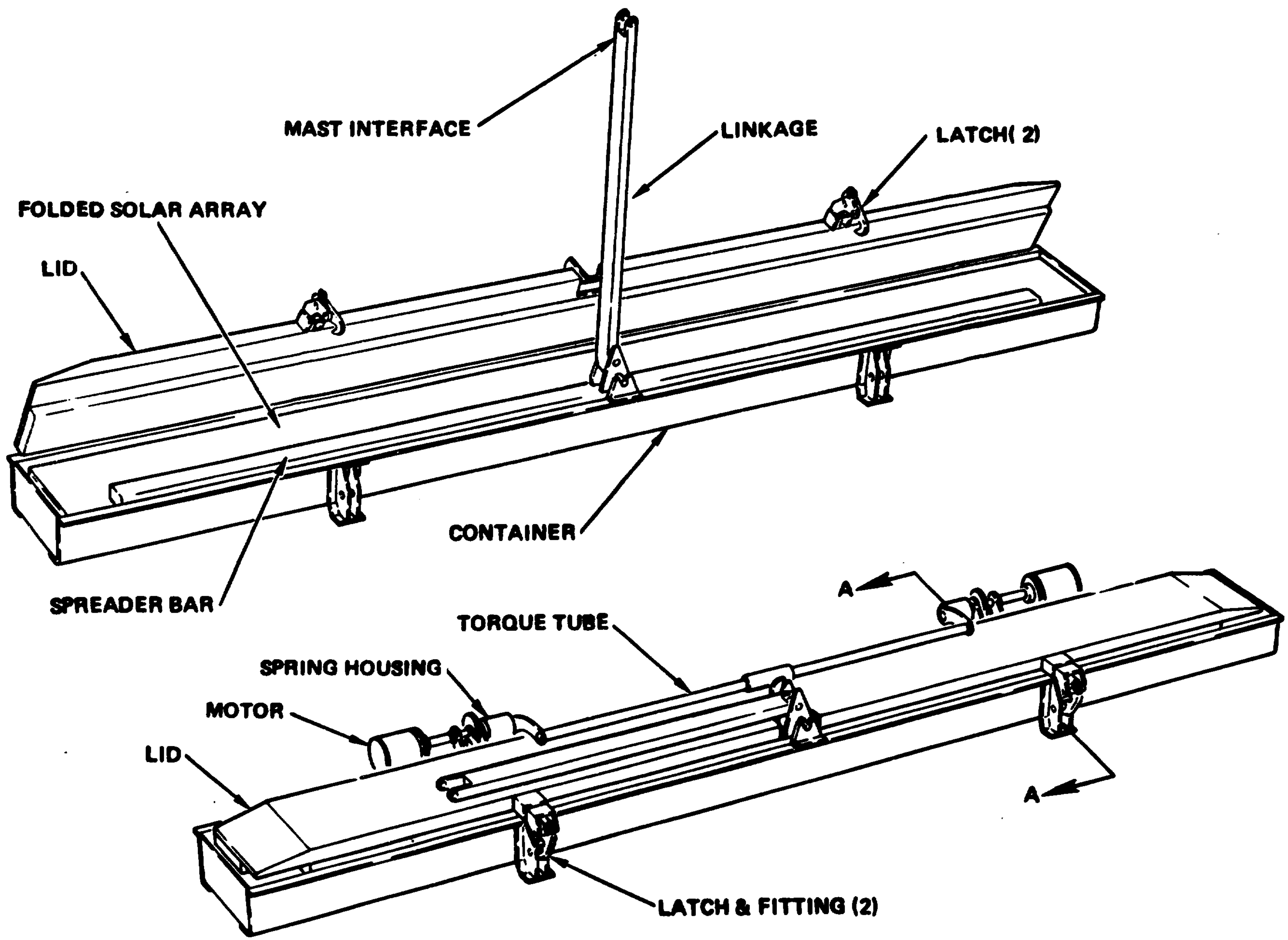


Figure 4. Blanket Housing Assembly Design

rotate since the blanket after refolding must be compressed slightly to survive re-entry. The lid is driven by redundant stepper motors through harmonic gears to shafts connected to torsion springs and the hinge/preload arm. Rigid links pass through the housing lid to the latch cam arms. The latches have cams that force both vertical translation and rotation as the linkages translate in the lid. A pin on the housing fitting provides the catch point for the latches as illustrated in Figure 5.

The blanket in the deployed configuration is maintained in tension by the deployment mast acting against a series of negator springs. These springs as shown in Figure 6 are distributed along the lower end of the bottom leader. The negators run through slots in the bottom of the container to take-up reels on the lower, outside surface of the housing as shown in Figure 7. The tensioning system is designed to maintain a minimum preload on the blanket for the plume and other deployed loading conditions and yet permit inplane rotation of the blanket.

The guide wire system consists of two long wires that run from the spreader bar at the tip to the base of the container. These guide wires run through holes in every other hinge of the blanket. The guide wire system is under a slight tension load throughout the blanket deployment and retraction sequence. It is used to control the position of the blanket panels when the blanket is partially deployed during deployment or retraction. The large take-up reels for the guide wire mechanism are also located on the lower outside surface of the housing as shown in Figure 7.

3.1.3 Mast/Canister

The solar array blankets are deployed and retracted with coilable, continuous longeron masts that are stored in a cylindrical canister device. The mast is a triangular truss structure with longerons of S-glass/epoxy that permit elastic coiling. The battens are rigid plastic members and the diagonals are either fiber glass or metallic wires. The canisters are of aluminum construction with the lower end a stowage region, the middle section used to transition the longerons from a coiled to a

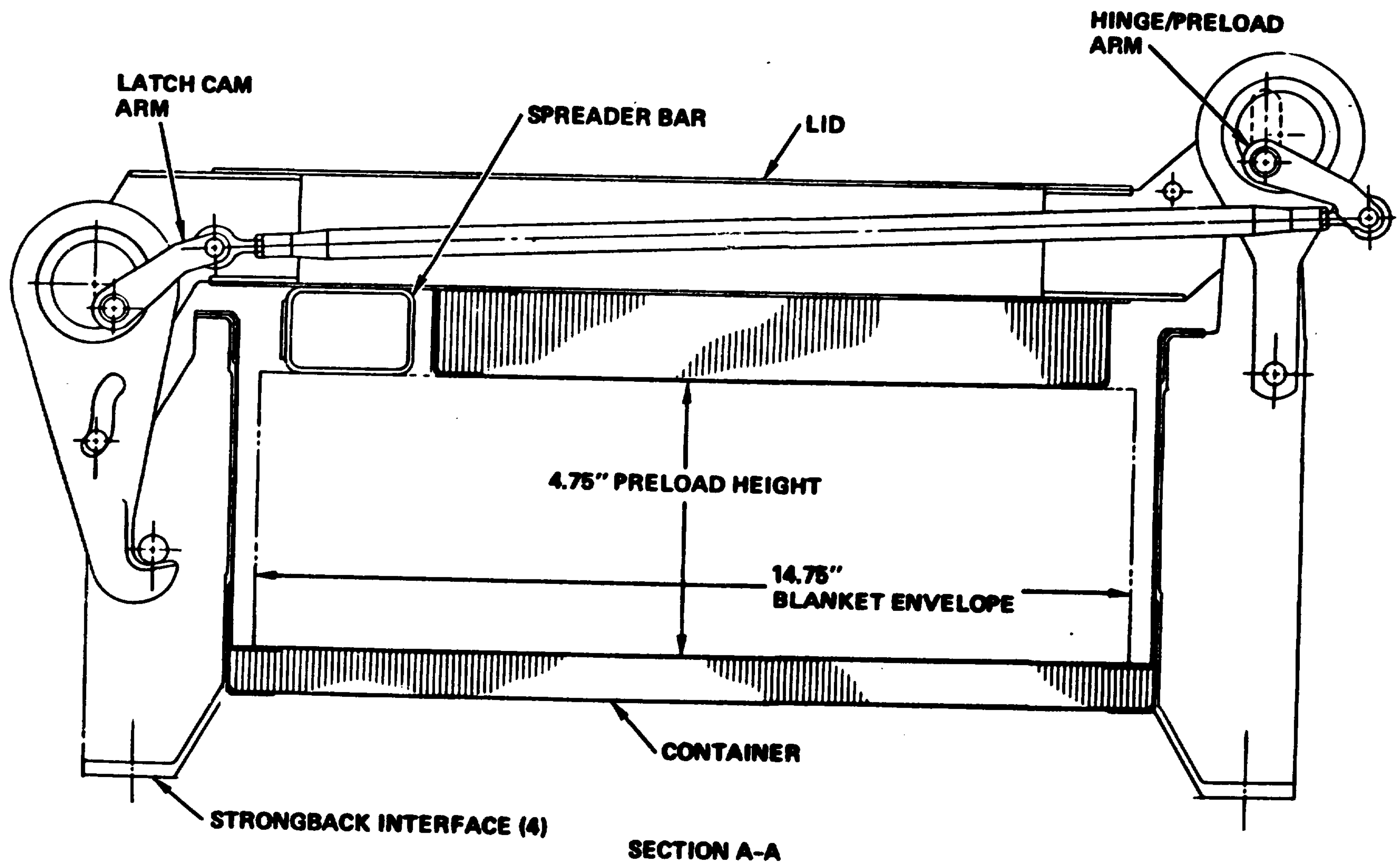


Figure 5. Latch and Preload Mechanism

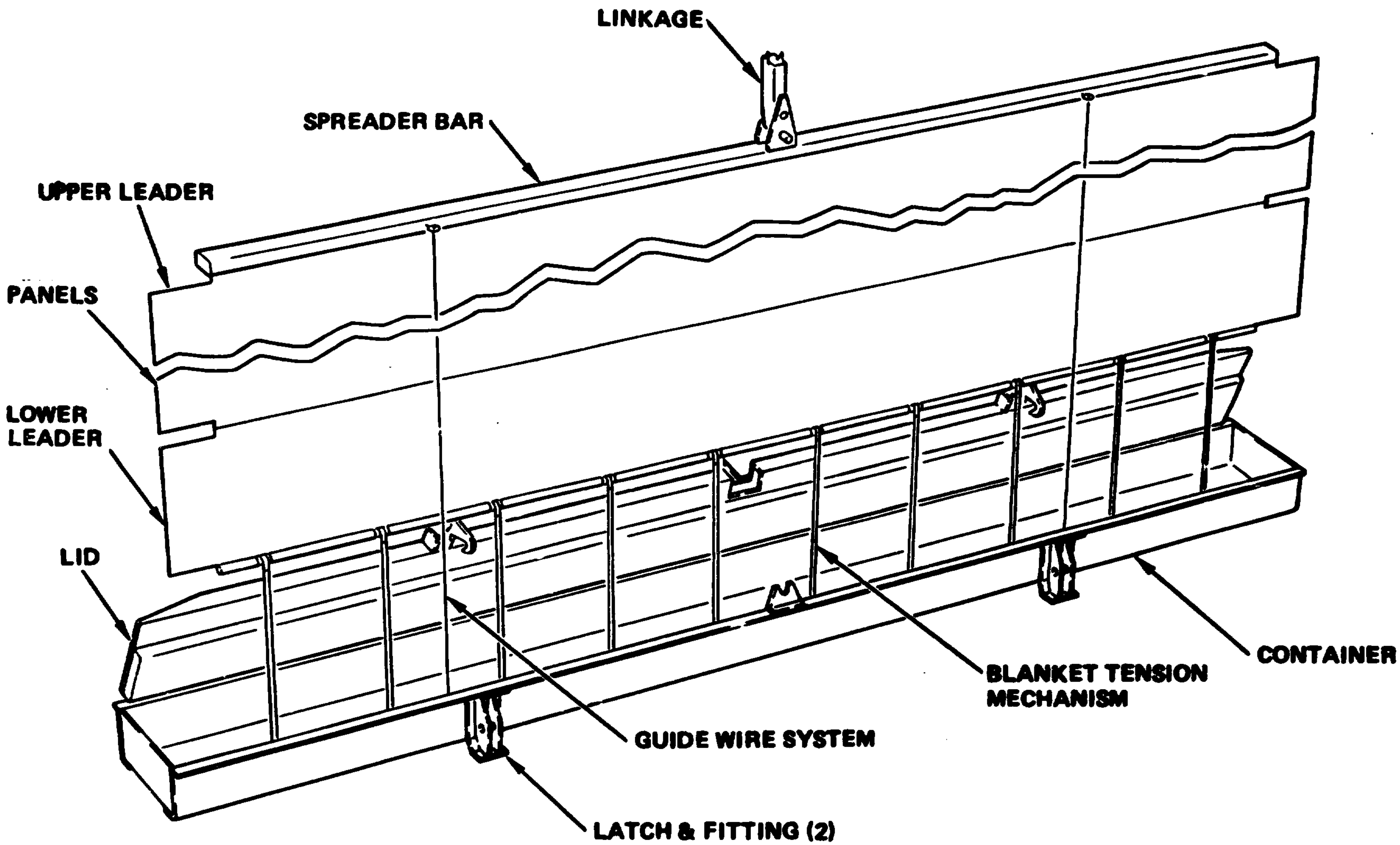


Figure 6. Deployed Solar Array Design Features

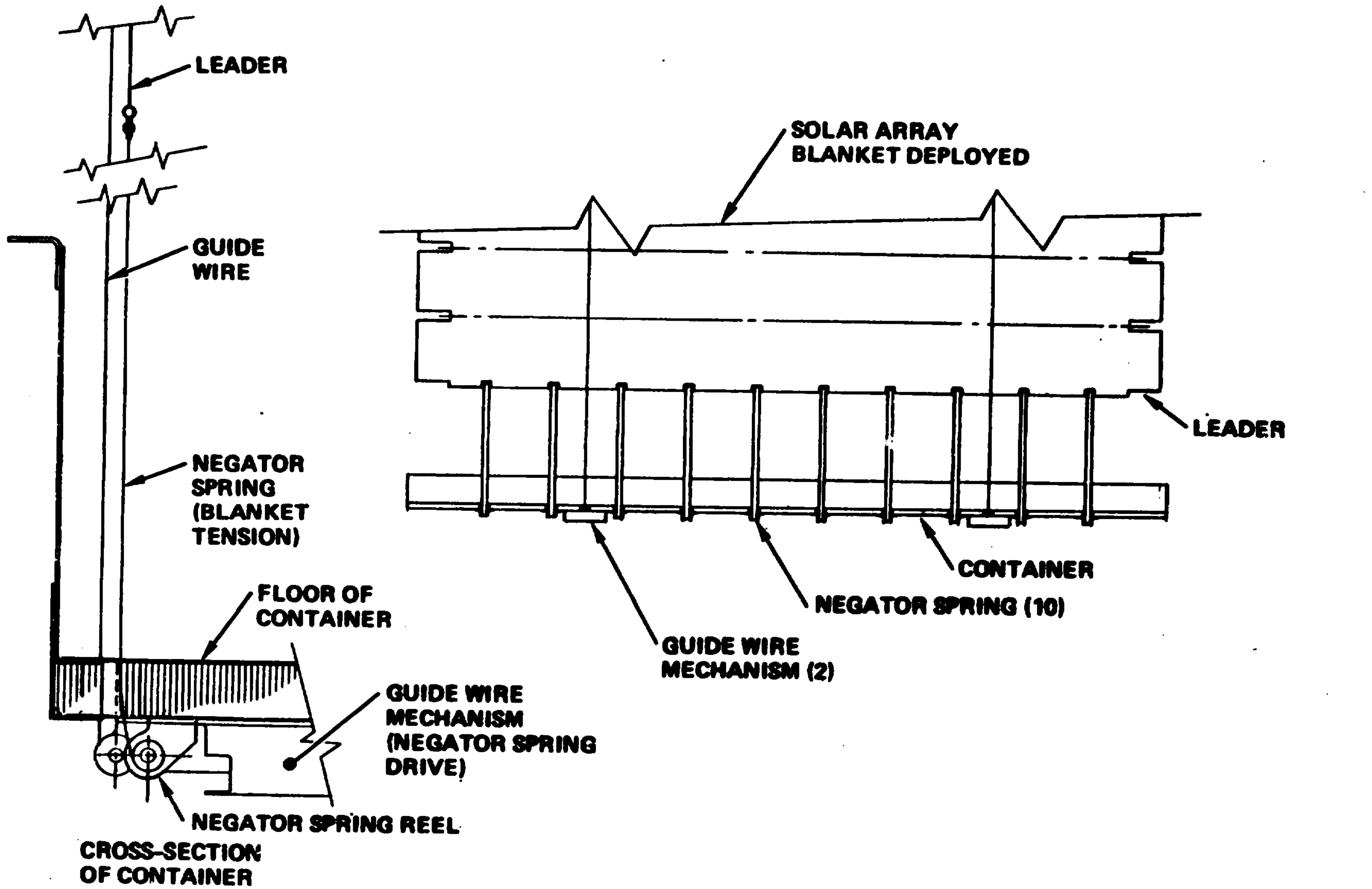


Figure 7. Blanket Tensioning and Guide Wire Mechanisms

straight configuration and the upper section for deployment and support. The upper section is a rotating nut driven by small electric motors and internally has three pairs of stationary vertical guide rails that engage round roller lugs on the mast longerons at the batten corners.

For the PEP application, a mast having a diameter of 19 inches and a length of approximately 1500 inches, has been tentatively selected based on an ultimate bending moment capability of 200 foot-lbs. The baseline design as designated by the System study contractor will use a rotating canister technique for storage reasons in the orbiter cargo bay; however, the TRW blanket housing design will not require the mast/canister design to provide the lid latching and blanket preload functions. Design features of the mast/canister assembly are illustrated in Figure 8.

3.2 Alternate Design

The principal design features of the PEP baseline solar array design are summarized in Figure 9. The alternate and baseline designs are identical as far as the mechanical features are concerned, however the solar cells in the alternate design are approximately 3 times the area of the baseline solar cell. There is a potential significant cost advantage to using a large solar cell assuming such a cell has been developed and qualified prior to its application to the PEP solar array. The alternate design briefly summarized here is based on the use of the large cell which has nominal dimensions of 5 x 5 cm.

In formulating the alternate design, certain assumptions were made on the solar cell performance. These included the design features of a 14% efficient, silicon cell with a polished front surface and a P^+ back surface field with back surface reflector. It is assumed to have the same conventional type of contacts but would use three interconnector devices rather than two. Cover glass features are the same as for the smaller cells.

The dimensions of the larger cells are selected to achieve maximum packing efficiency in the overall space and still meet the voltage levels as specified in the solar array requirements. Since the volume allowance did not change the panel dimensions remain the same. Working

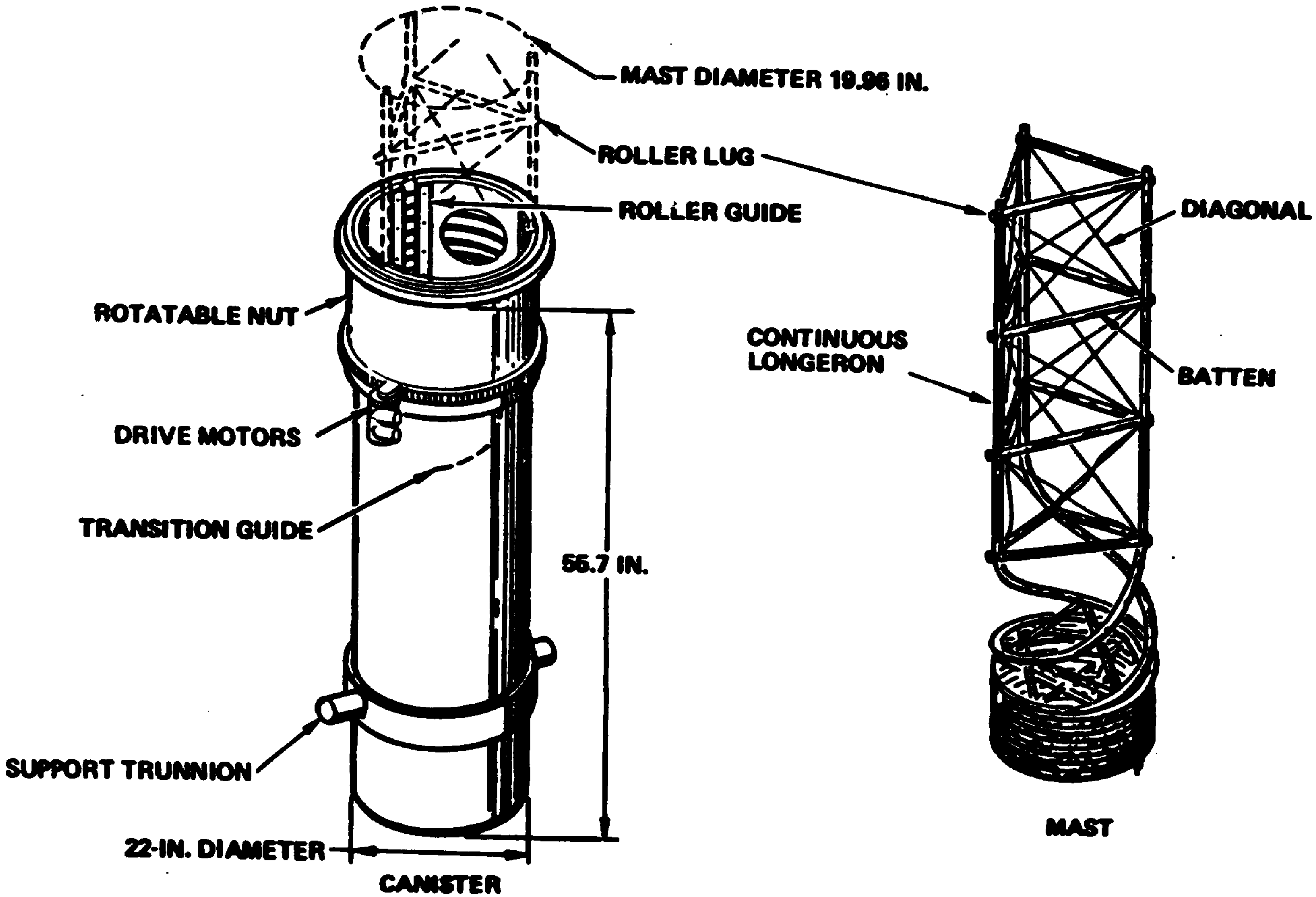
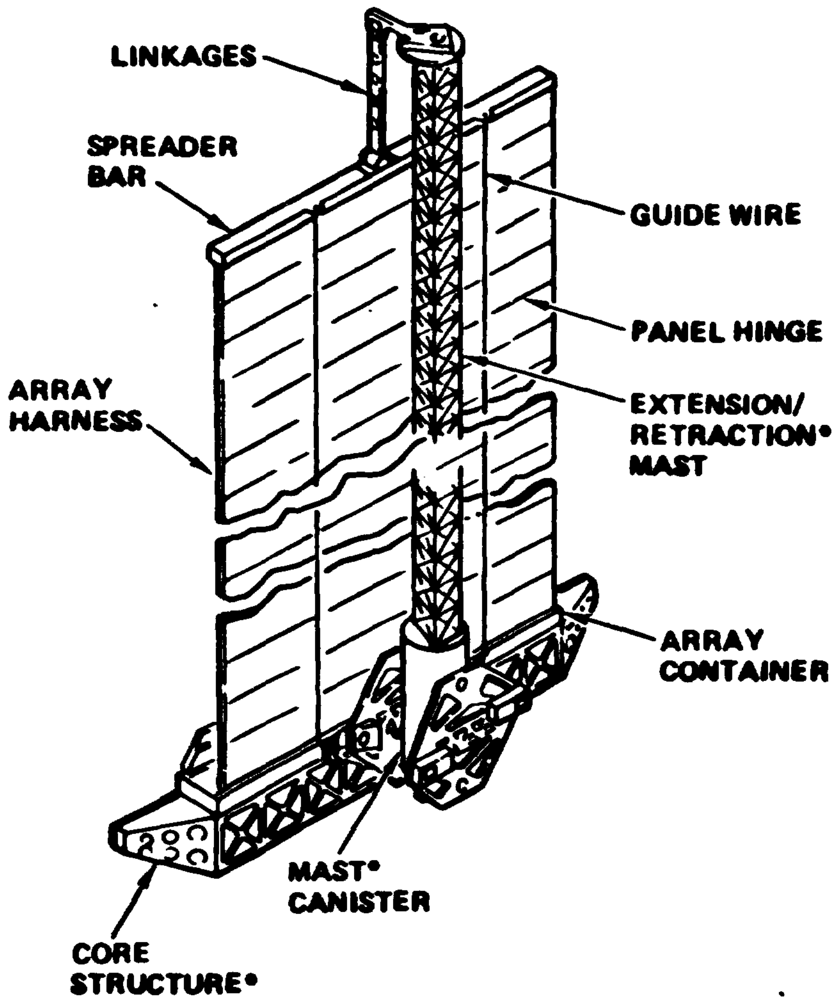


Figure 8. Mast/Canister Assembly



*SYSTEM CONTRACTOR ELEMENTS

DESIGN FEATURES

• SOLAR CELLS	– 2.22 x 3.96 CM 8 MIL THICK 14% EFFICIENCY CONVENTIONAL SOLDERED INTERCONNECTS
• COVER GLASS	– 6 MIL MICROSHEET
• SUBSTRATE	– 2 PLIES OF ONE MIL KAPTON WITH INTEGRAL RIB STIFFENERS
• PANEL SIZE	– 0.36 x 3.81 M
• WING SIZE	– 102 PANELS 3.81 x 37.0 M 140.9 M^2 AREA
• POWER OUTPUT (BOL) (PER WING)	– 16.4 KW

Figure 9. PEP Baseline Solar Array Summary

within these constraints the individual cell dimensions evolved to 5.7 x 5.3 centimeters with the orientations illustrated in Figure 10 and the solar array wing properties summarized in Table 1. With the smaller number of cells in series the voltage per panel decreased from 63 to 25 volts. By wiring 6 panels in series rather than 2, the overall wing voltage is within the allowable range. Minor changes to the harness would be required, and there would be a reduction in the electrical modularity from 51 to 20.

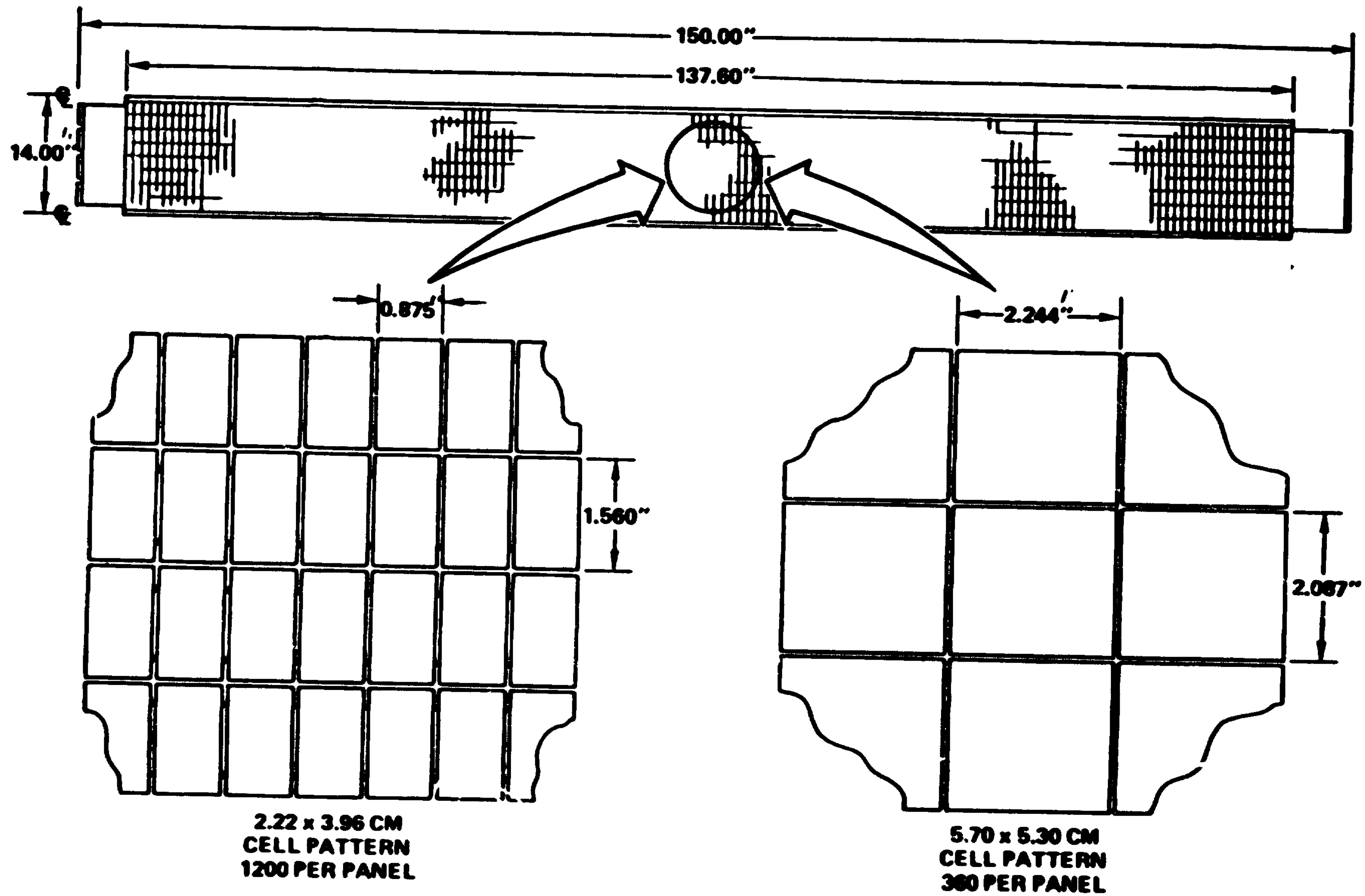


Figure 10. Alternate Solar Cell Panel Design

PARAMETERS	WING CONFIGURATION	
	2.22 x 3.96 CM SOLAR CELL	5.70 x 5.30 CM SOLAR CELL
PANEL WIDTH – IN. (℄ TO ℄)	14.00	14.00
PANEL LENGTH – IN.	150.00	150.00
NO. OF PANELS	102	100
NO. OF LEADERS	2	2
BLANKET LENGTH – IN.	1456.00	1428.00
CELL THICKNESS – MILS	8	8
COVER THICKNESS – MILS	6	6
NO. OF CELL/PANEL	1200	360
TOTAL NO. OF CELLS (10^3)	122.4	36.0
WEIGHT (LBS)	355	357

Table 1. Baseline and Alternate Wing Design Data

4.0 PROGRAM PLAN

This program plan presents the management and implementation techniques to accomplish the design, development, manufacturing, test and delivery of the solar array assemblies for the Power Extension Package (PEP). The PEP System is used on the Space Transportation System (STS) for the purpose of providing auxiliary power during earth orbit missions. This plan is specifically oriented to the requirements of a proto/flight concept and to meet required delivery dates while keeping expenditures within the fiscal year funding constraints.

The management details of the plan describes the project organization and responsibilities, and the project schedules. The key management task of the PEP Program is to meet the delivery schedule for flight certified solar array assemblies while keeping expenditures within the funding constraints for fiscal 1981, 1982 and 1983.

The Design and Development phase of the plan details the PEP wing design activities during the first 16 1/2 months of the program. Emphasis is placed on system interface requirements and development verification testing including a full scale engineering model wing assembly. This activity is concluded at the Critical Design Review (CDR) and begins the manufacturing phase. The Manufacturing activities are briefly summarized by showing a step by step flow for the fabrication of the PEP solar array wing assembly. The methodology and span times reflect the experience derived from present manufacturing process and techniques. A detailed discussion of facilities and manufacturing plans are presented in Section 5 of this document.

The Assembly and Test activities cover the implementation of the qualification (proto/flight) and flight model verification test plan. Block diagrams with accompanying explanations depict each major step in the verification process. This plan will include the operational support activity to the prime contractor plus launch support activity at KSC.

4.1 Management

The PEP solar array project will be managed within the Space Systems Division of TRW Defense and Space Systems Group using standard TRW project control procedures and relying on the currently operating cost and schedule

reporting systems. The organization and control of the project will be tied to the work breakdown structure. A proposed organization structure is presented in Figure 11, along with a definition of major activities in each group.

A major area of emphasis in the PEP Project Management activities is with the solar cell manufacturers. Since the solar cells are a significant factor in the solar array performance and constitute a large fraction of total project costs, special emphasis will be placed on management of the solar cell subcontract. During the design and development phase, a technical specialist will be assigned to work with the subcontract manager to monitor the technical design and development of the solar cells. In addition, it is anticipated that significant interfacing with the system contractor will be required, therefore Mechanical Design Integration (MDI) and Electrical Design Integration (EDI) functions in the System Engineering cell will be established to work these interfaces in great detail.

The program plan activities related to the baseline and minimum schedules, verification, and mission support are discussed in the following sections.

4.2 Baseline Schedule

The PEP solar array wing assembly baseline schedule is as shown in Figure 12. The schedule is structured about program milestones directed by NASA/JSC. The key feature of the project schedule is to deliver the first flight unit within the funding constraints for fiscal 1981.

4.2.1 Design and Development

The design and development phase of the baseline schedule is a 16 1/2 month time span starting at ATP and concluding at Critical Design Review (CDR).

This phase starts with the systems engineering effort of requirements definition with a Preliminary Requirements Review (PRR) at month 3 to summarize the interface and design requirements. Following the PRR is the initiation of design for the flight wing and the release of engineering model hardware drawings at month 8 Preliminary Design Review (PDR). The Critical Design Review (CDR) occurs at program month 16 1/2 and

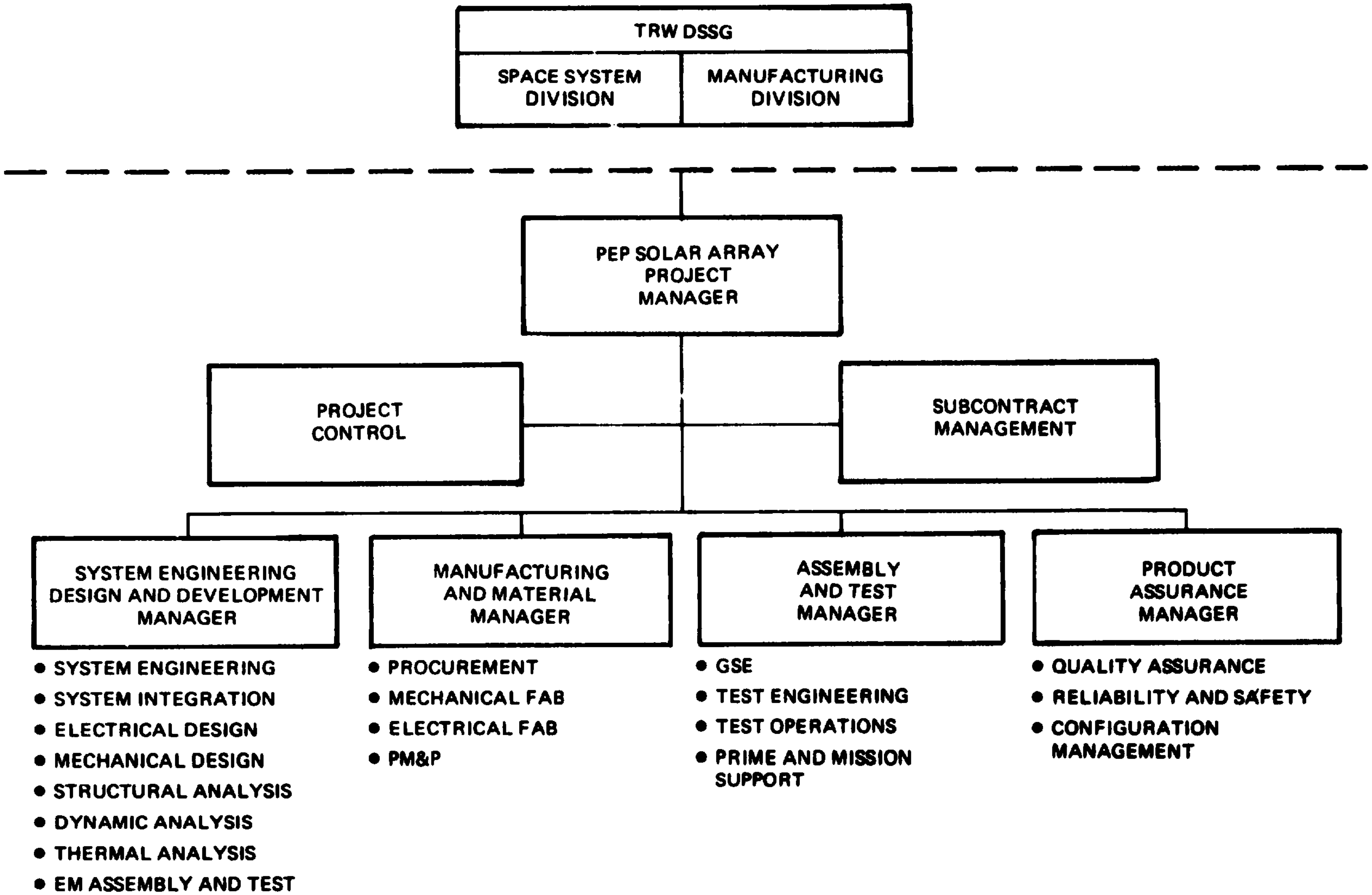


Figure 11. PEP Solar Array Project Organization Structure

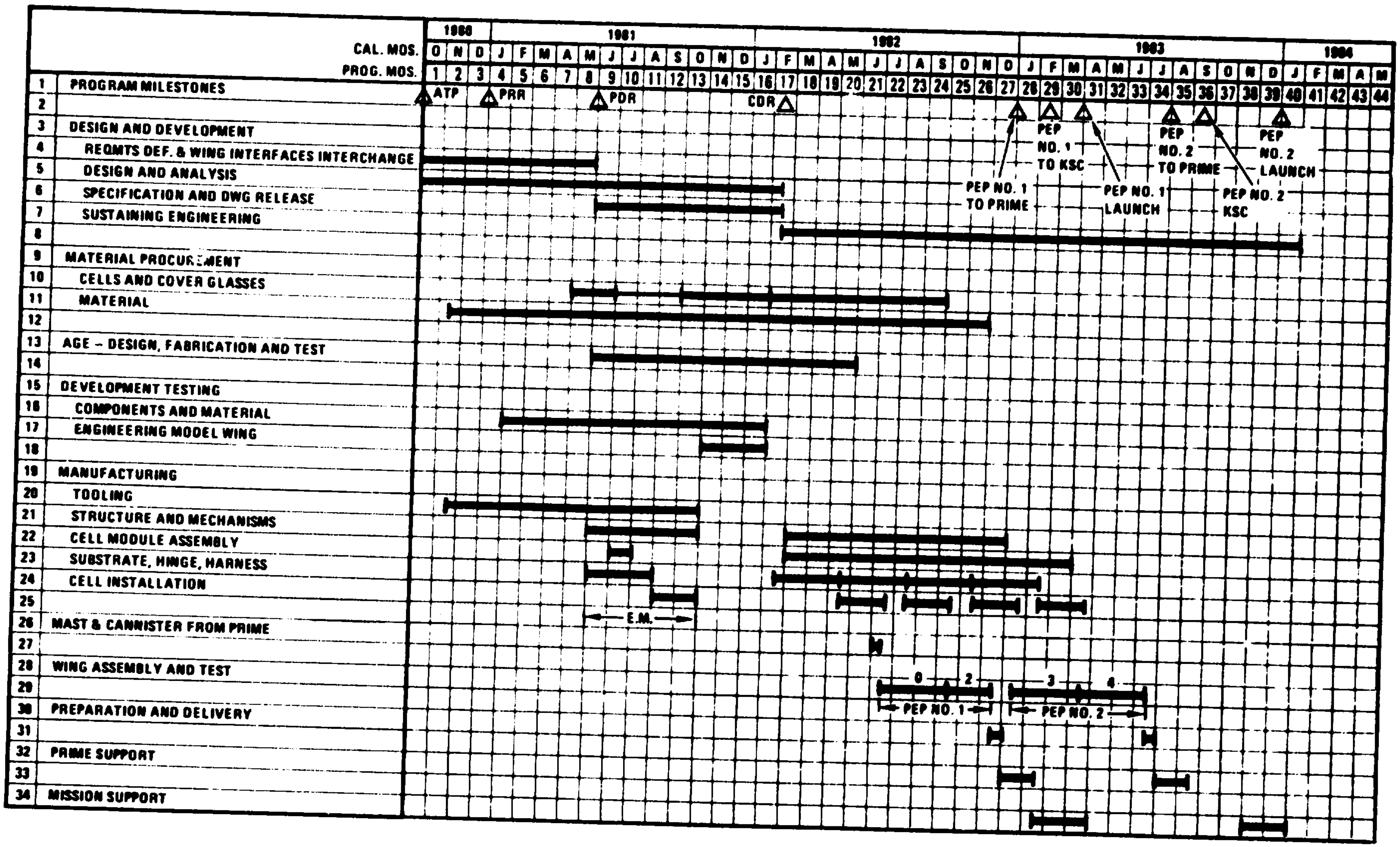


Figure 12. PEP Solar Array Project Baseline Schedule

is preceded by the completion of all development and engineering model testing and release of flight wing assembly drawings and specifications. Sustaining engineering to support Manufacturing, Assembly and Test, and Prime and Mission support will be required from the completion of CDR to the launch of PEP No. 2. The design and development activities for the Solar Array Assembly and the Ground Support Equipment are illustrated in Figure 13.

4.2.2 Material Procurement

Material procurement required to support hardware development and the Engineering Model Wing Assembly starts 1 1/2 months after ATP. Solar cell and cover glass procurement for the proto/flight wing assembly is initiated at Month 13 and first cell delivery is at Month 17 with a delivery rate 12,000 cells per week for fifty weeks.

4.2.3 Ground Support Equipment (GSE)

The engineering design, fabrication and test activities as shown in Figure 13 for the GSE required to support the assembly, test, delivery and launch of the PEP Solar Wing Assembly commences at the completion of PDR at Month 8, and concludes at Month 20. Handling and test fixtures required to support engineering model testing will be completed by Month 14 with the remaining GSE being completed before the start of assembly and test of the proto/flight (Qualification) solar wing assembly.

4.2.4 Development Testing

The development testing activities as shown in Figure 14 is time-phased to be completed by CDR and is divided into two sections; component and material testing and engineering model testing. The component and material testing starts at program Month 5 and completes 12 months later. The full scale engineering model wing assembly consisting of flight type substrates, hinges, harness, and simulated cells and cover glasses (a selected number of live cells will be used) will be tested over a 3-month span starting at Month 14. The major tasks in the engineering model test wing program include deployment and retraction tests before and after the dynamic environment tests of vibration, acoustics and shock.

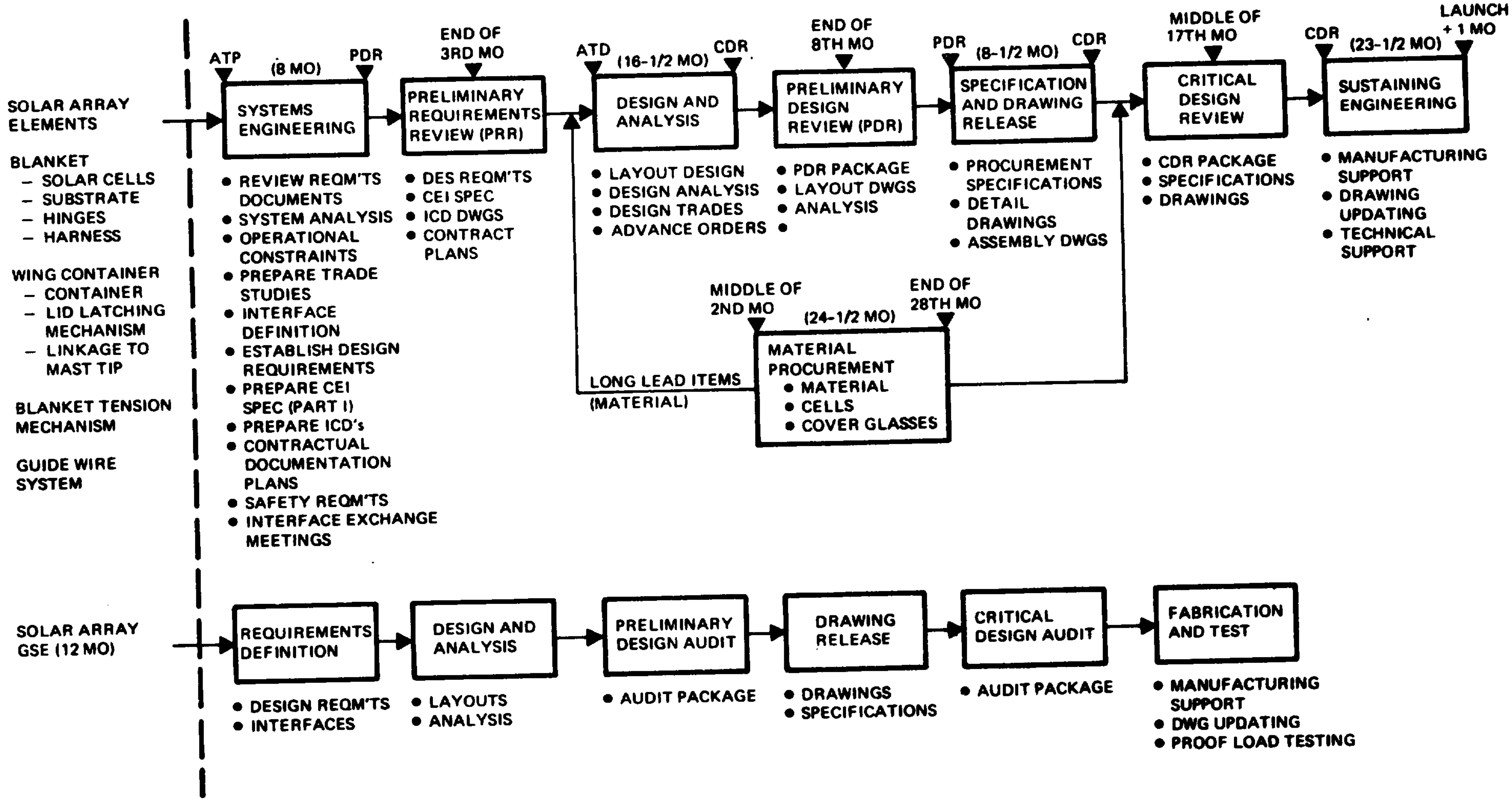


Figure 13. Baseline Schedule for Design and Material Procurement

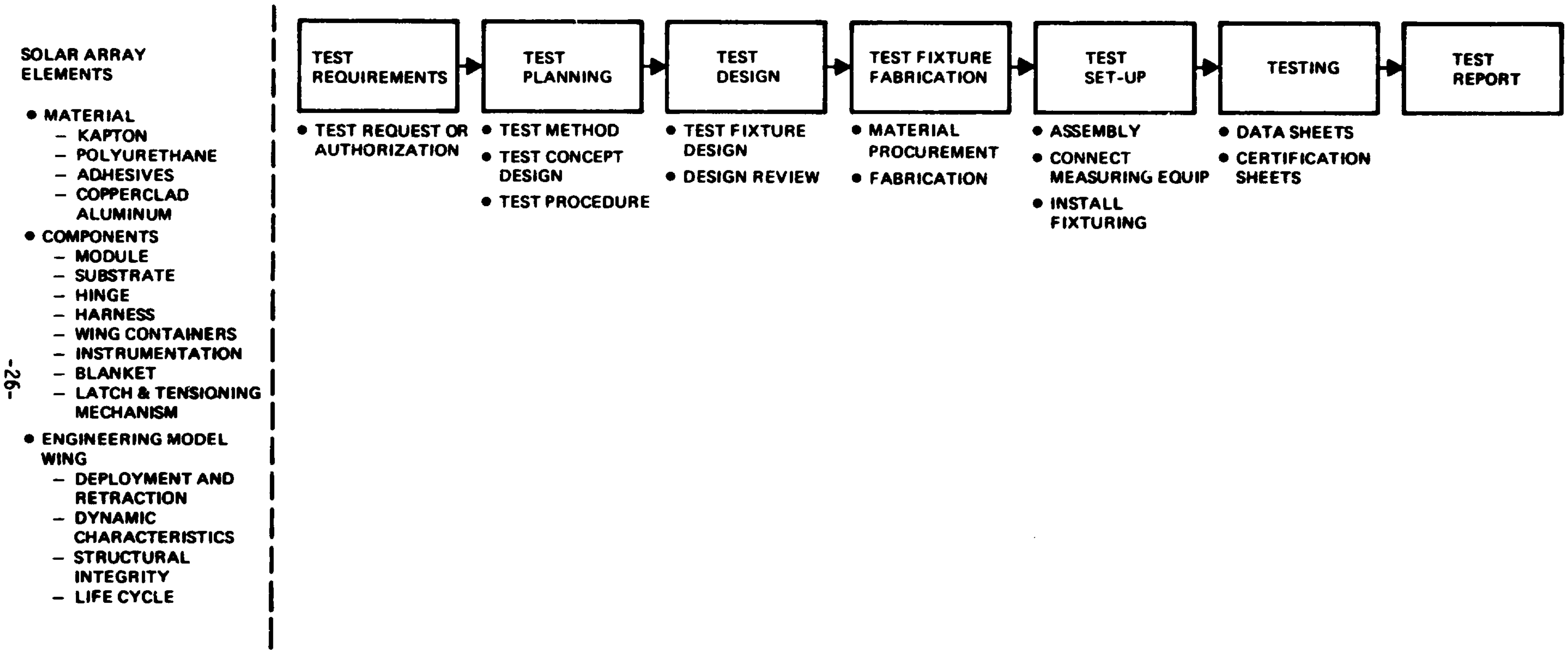


Figure 14. Development Testing

4.2.5 Manufacturing

The manufacturing activities as shown in Figure 15 and as further delineated in more detail in the Manufacturing Plan of Section 5 starts with the design of tooling for the substrate. Early design and procurement of the substrate tooling is required to support the engineering model wing fabrication. This activity starts 1 1/2 months after ATP with tooling ready to support the manufacturing of the engineering model substrate at month 9. The manufacturing span for development hardware is 5 months starting at month 9 and concluding at month 14.

The manufacturing of flight hardware starts at the completion of CDR (month 16 1/2) and finishes at program month 30 1/2 for a span of 14 months. The major drivers and ground rules to arrive at this schedule are as follows:

<u>Cell Delivery</u>:

- Assumes two cell vendors with a capacity of 15,000 cells per week for a total capacity of 30,000 cells per week. The solar cell manufacturing capability should be able to meet the PEP need of 12,000 cells per week and still satisfy other requirements.
- Due to Fiscal Year 1981 funding constraints purchase of cells was delayed until Fiscal Year 1982.

<u>Cell Preparation</u>

- The semi-automated cell processing facility will be operated at a rate of 2400 cells per day on a one shift, five days per week. This makes full utilization of the 12,000 cells per week delivery rate and results in a cost effective use of both labor and existing facility capability.

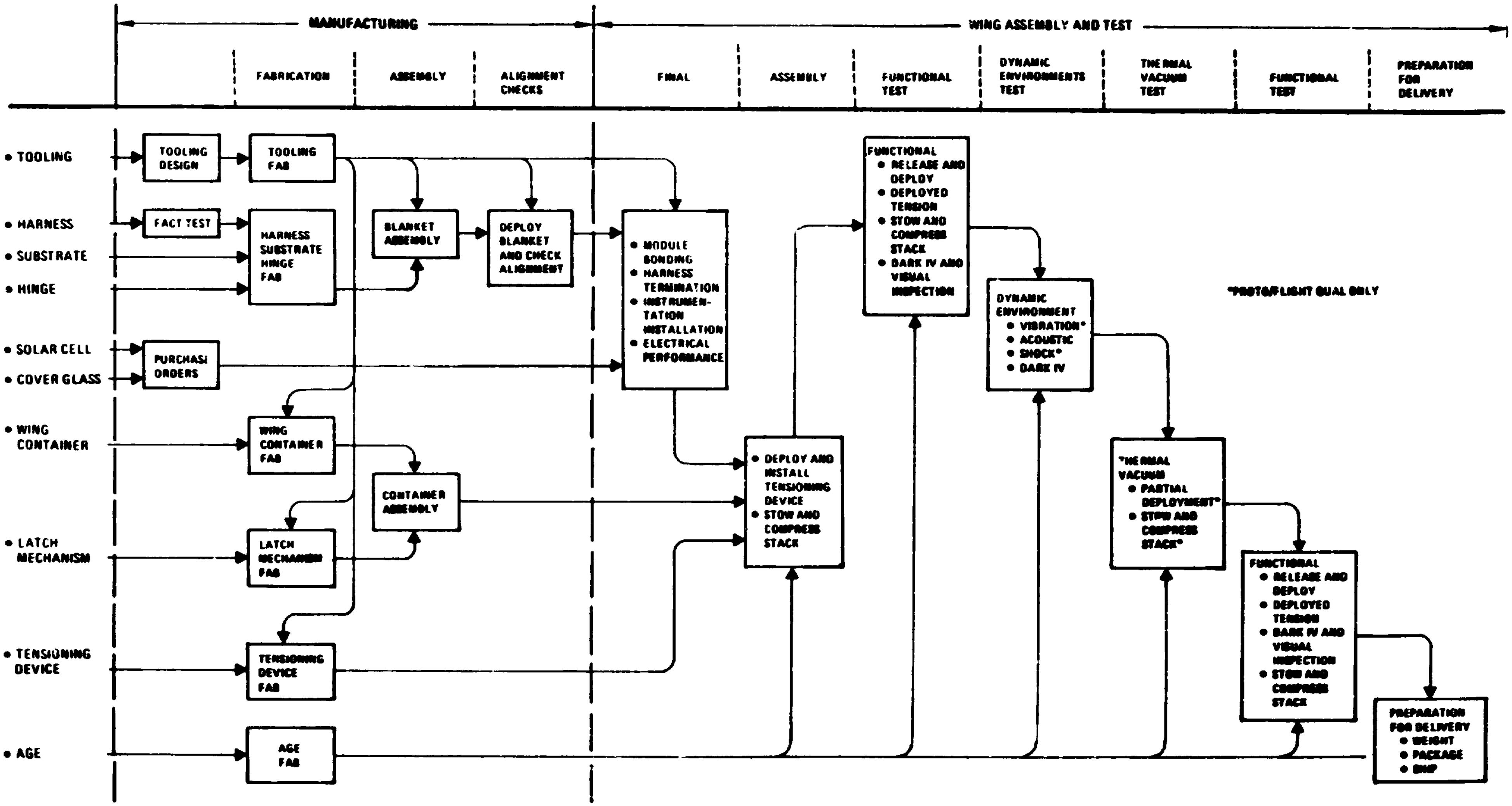


Figure 15. Manufacturing, Assembly and Test Flow

Substrate, Hinges and Harness

- Three months were allotted for the fabrication and assembly of the solar array blanket assembly. This time span was arrived at by cost trades between different number of tooling sets versus reduction of manufacturing and assembly time spans. From these studies the production rates for the panels are 4 panels/shift x 2 shifts; hinge installation are 4 hinges/shift x 2 shifts; and harness installations are 4 panels/shift x 2 shifts. Since these steps are in series, 49 working days are required to fabricate and assemble the substrate blanket. Allowing 20 working days per month this schedule allows 11 days for contingency.

Module Installation

- Three months are allowed for module installation. This is based on a single shift operation with an installation rate of 2400 cells per day (2 panels). Installation time is 51 working days which allows a 14 day contingency in the schedule.

4.2.6 Wing Assembly and Test

The Wing Assembly and Test activities are shown on Figure 15. These scheduled activities are based on one proto/flight (Qualification) wing and three flight wings. Three months are allowed for the assembly and test of the qualification wing and two months for the flight wing for the first PEP system. Assembly and test span for the second PEP System is three months per wing and is based on the required program delivery date. This gives a one month contingency for the delivery of the second PEP System

4.2.7 Preparation for Delivery, Prime Contractor and Mission Support

Two weeks are scheduled for the preparation and shipment, six weeks for prime contractor integration support and ten weeks for launch support.

(six week prelaunch and four weeks post launch.) The time span for preparation and delivery and prime support for PEP No. 2 is the same as PEP No. 1, but the launch support has been reduced from 10 to 8 weeks.

4.3 Minimum Schedule

A PEP Solar Array Minimum Schedule is presented in Figure 16. This schedule reflects the solar array program activities without the funding constraints of 1981, and assumed the following:

- o Revised program milestone dates as shown in Figure 16.
- o No Fiscal Year 1981 funding constraints.
- o Cell delivery rate same as baseline schedule but with earlier start date.

4.3.1 Key Features of Minimum Schedule

Some of the key features of the minimum schedule compared to the baseline schedule are:

Program Milestones

PRR	- 1 month earlier
PDR	- 2 months earlier
CDR	- 4 1/2 months earlier
PEP No. 1 to Prime	- 3 1/2 months earlier
KSC Activities	- 3 1/2 months earlier
PEP No. 2 to Prime	- 5 1/2 months earlier
KSC Activities	- 4 1/2 months earlier

Design and Development

Requirements definition reduced by 2 months.
Design and Analysis reduced by 4 1/2 months.
Specification and Drawing release reduced by 4 1/2 months.
Sustaining Engineering reduced by 4 1/2 months.

Material Procurement

Cell and cover glass procurements start 1 month after ATP (10 1/2 months schedule).

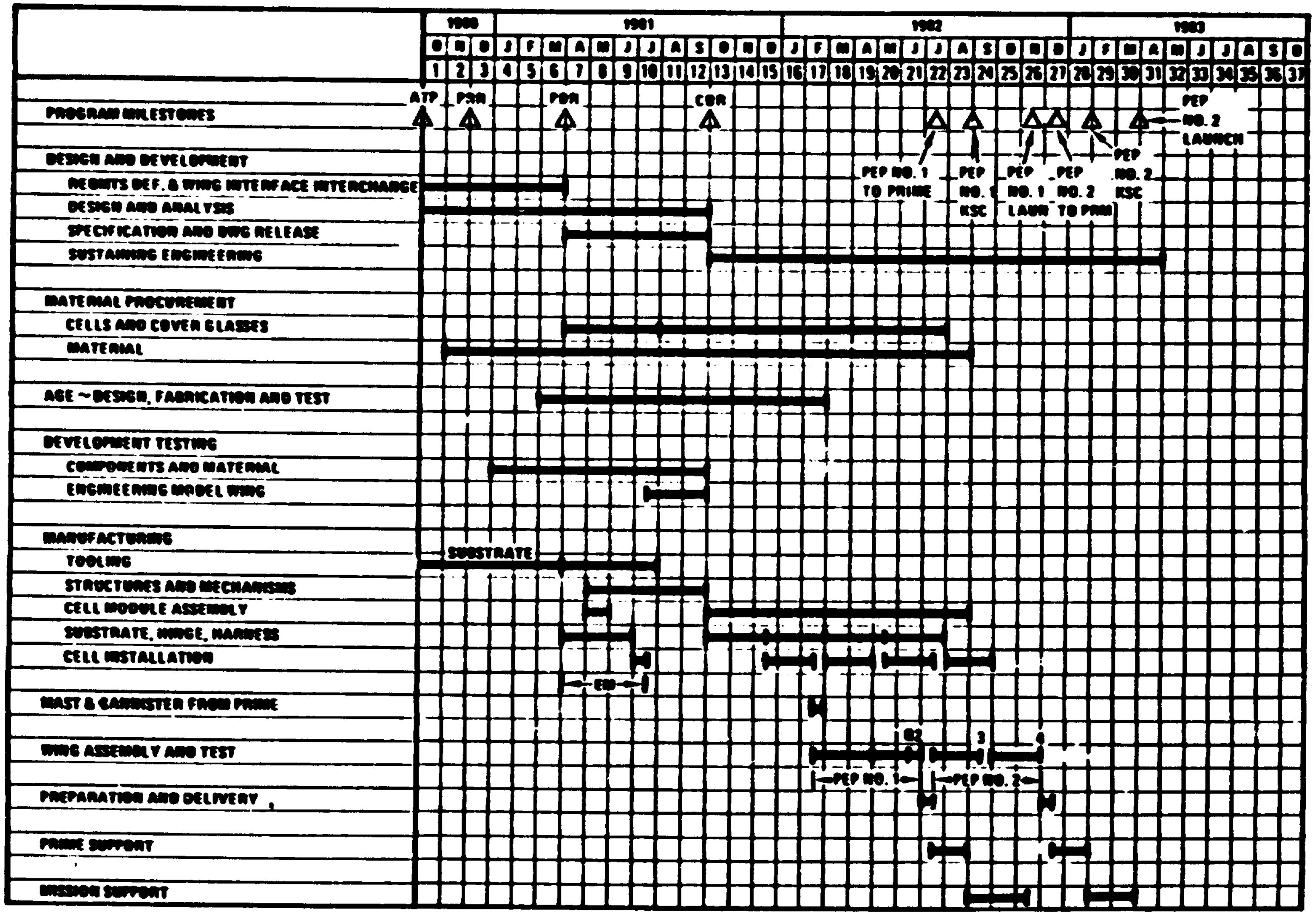


Figure 16. PEP Solar Array Project Minimum Schedule

Development Testing

Component Testing starts 1 month earlier.

Engineering Model Wing starts 4 months earlier.

Manufacturing (Engineering Model)

Tooling design for substrate starts at ATP, substrate, hinge, harness moved ahead 2 months.

Cell installation moved ahead 2 months

Proto/Qual Unit

Structures and mechanisms moved ahead 1 month.

Cell module assembly moved ahead 5 months.

Substrate, hinge, harness moved ahead 4 1/2 months

Cell installation moved ahead 4 1/2 months

Wing Assembly and Test

Moved ahead 4 1/2 months

Preparation and Delivery

PEP No. 1 moved ahead 4 1/2 months.

PEP No. 2 moved ahead 5 1/2 months.

4.3.2 Minimum Schedule Risks

Along with the advantage of reducing the total program span by 9 months using the minimum schedule, potential risks are also apparent. Early design definition will be required on the solar cell size and substrate to allow tooling design and fabrication for completion of substrate manufacturing at the end of Month 9.

4.4 Development Testing

The Engineering Development Test Program for the design and development of the solar array will consist of material, component and full scale wing assembly tests as shown in Figure 17. These tests will acquire engineering design information and confirm material and component characteristics to be used in the development of the design to meet the solar array design and performance requirements.

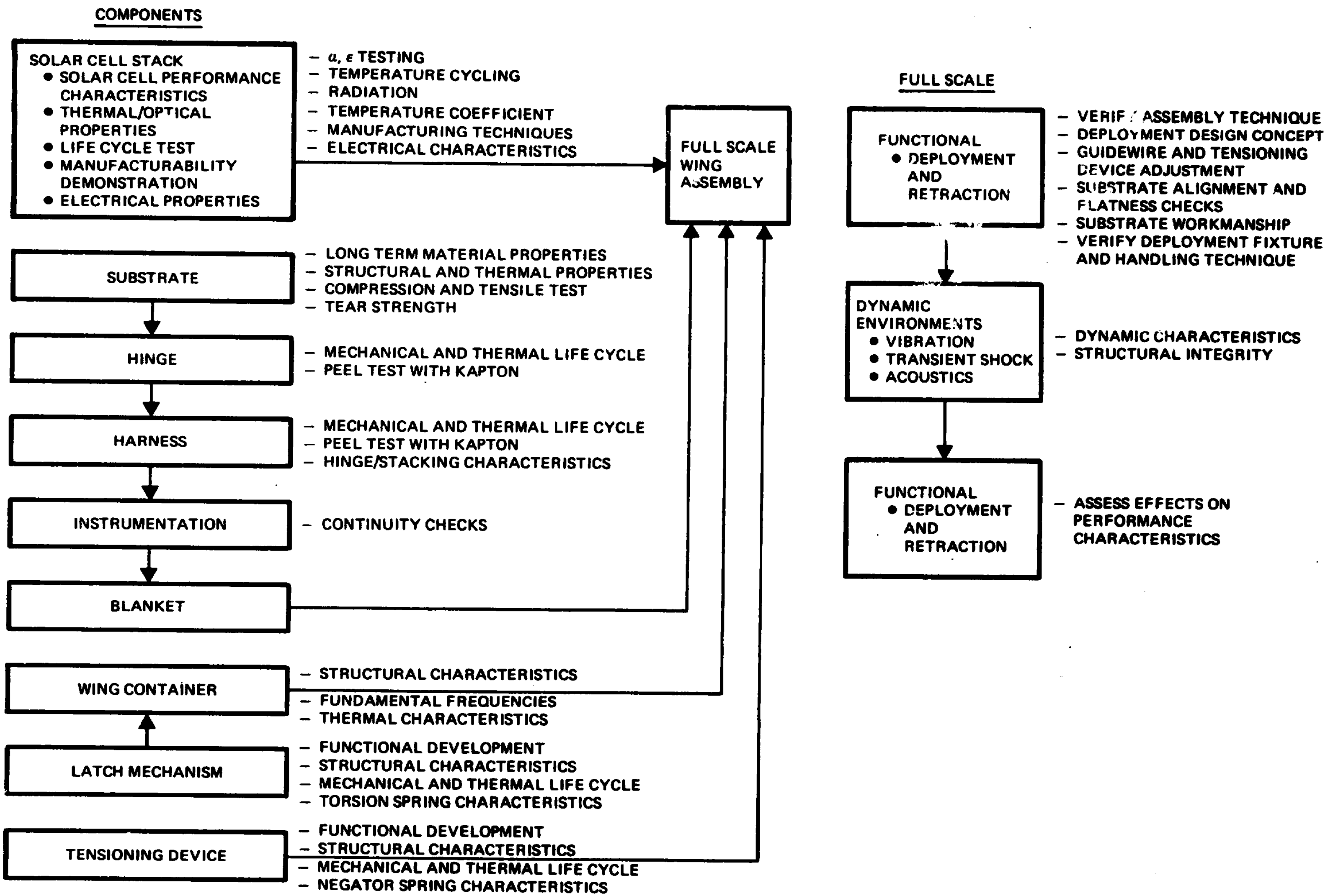


Figure 17. Engineering Model Development Test Program

4.4.1 Material Tests

Various material tests will be performed and the data required are shown in the following table:

Material	Data Required
o Adhesive	Physical characteristics Long Term Material Properties Thermal Characteristics Peel Characteristics
o Kapton	Peel Test with hinge and harness Tear and cutting characteristics
o Hinge Spacer	Thermal Properties Stiffness Density
o Wire	Physical characteristics (stretch, etc.) Corrosion resistance
o Graphite Composites	Structural characteristics.

4.4.2 Component Tests

Solar array component tests to be performed and the data to be acquired are shown in Figure 17. These tests will be performed using pre-production component test articles and the full scale engineering model wing assembly.

4.5 Solar Array Verification

4.5.1 Qualification Testing

The Qualification Test Program shown in Figure 18 will be performed to qualify the solar array components and wing assembly. These tests will demonstrate that the hardware items will perform within the required tolerances over the range of operational and environmental criteria specified in the applicable solar array subsystem specifications. Where practical, components will be qualified by similarity.

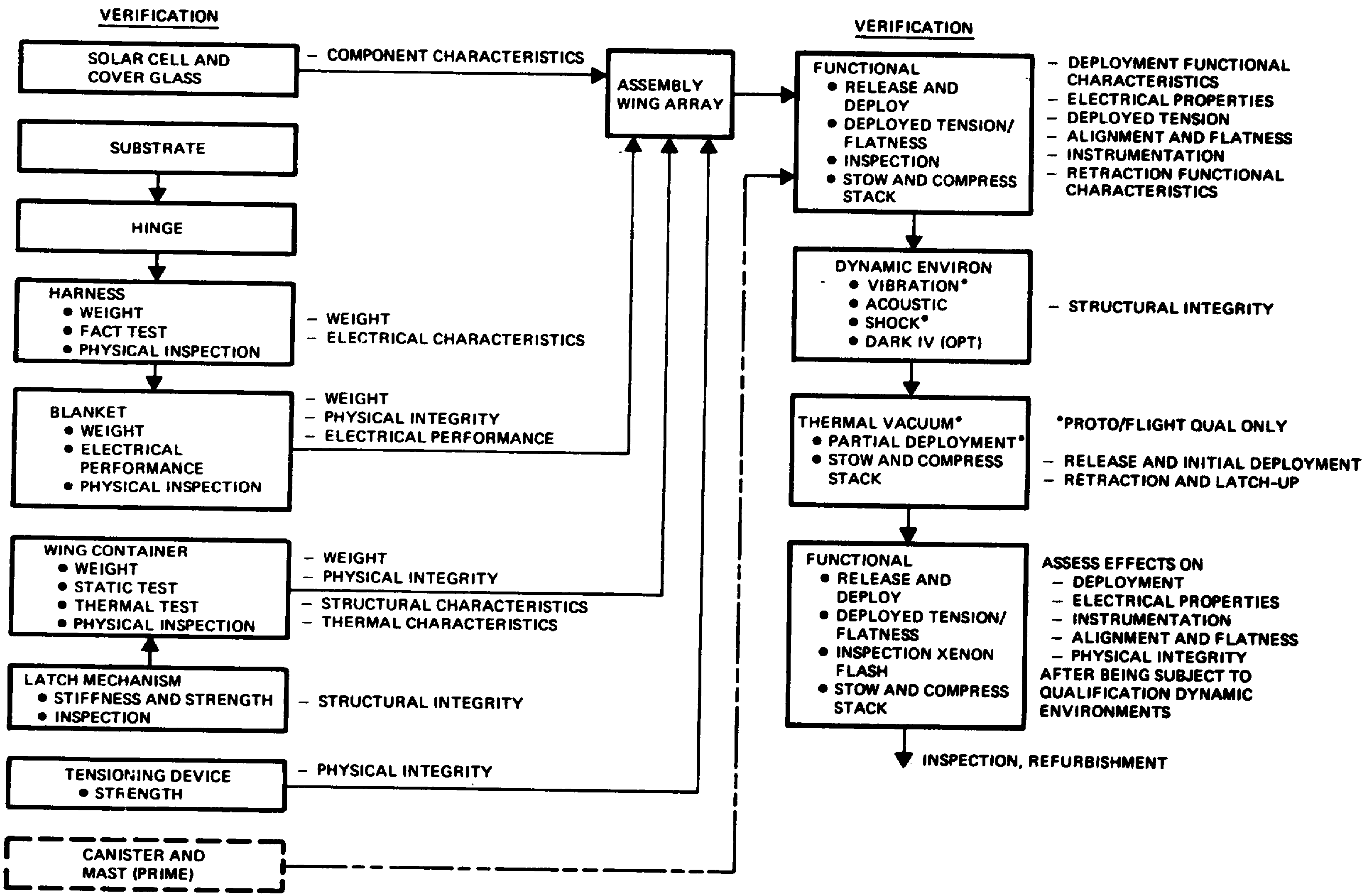


Figure 18. Qualification Testing

4.5.2 Acceptance Testing

The Acceptance Test Program shown in Figure 19 will be performed to demonstrate acceptance of the hardware for delivery to the using location. These tests will be performed at the solar array component and wing assembly level to demonstrate that the hardware items will perform as delineated in the test requirements, drawings and specifications. The solar array wing assembly will be functionally tested and accepted prior to delivery.

4.6 Prime and Mission Support

The solar array contractor has the responsibility of providing technical and hardware maintenance support after the hardware is delivered. During the integration phase following first delivery, this support would be at the prime contractor's facility initially, and then at the launch facility (KSC or VAFB) for mission support once the PEP system is delivered. Following the qualification flights of the PEP systems, there would be an operational phase requiring additional support. The preliminary planning related to these phases are summarized in the following sections.

4.6.1 Prime Support

The prime contractor will be responsible for integrating the solar arrays into the PEP system and performing the system level verification activities. Since the baseline schedule requires delivery of the first solar array approximately six weeks before delivery of the PEP system to KSC the activity at the prime contractor facility will be minimal. The principal tasks will be support to the mechanical and electrical integration of the wings into the array deployment assembly. Acceptance testing with the integrated hardware will be primarily functional and electrical continuity checks. Based on discussions with the system study contractor the tests may include the following items.

- Operational sequence
- On-line power performance evaluation
- Dark IV testing
- Partial array deployment

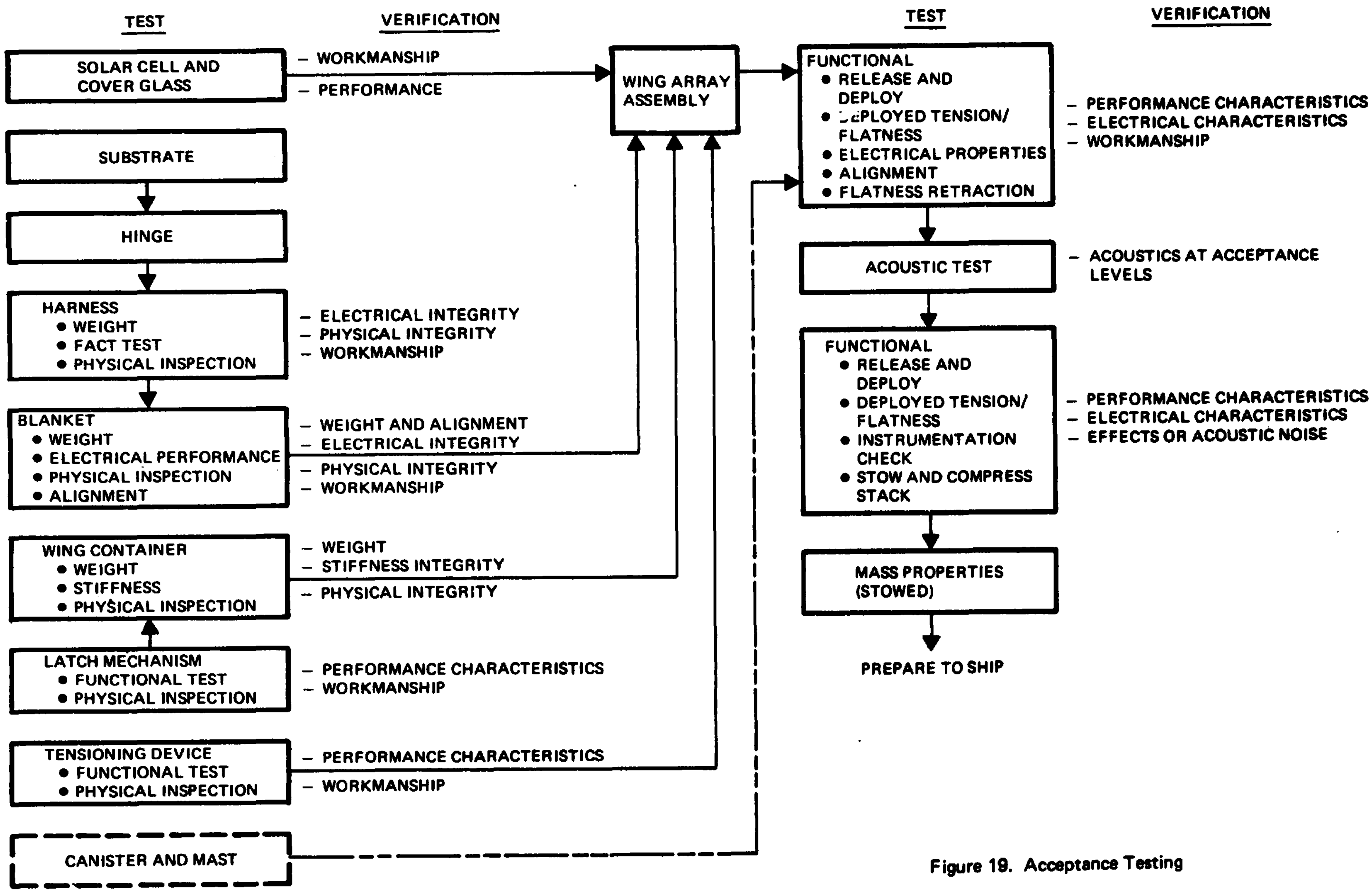


Figure 19. Acceptance Testing

Preparation and shipment of the PEP system and supporting GSE to KSC or VAFB will be supported by the solar array contractor as required.

4.6.2 Mission Support

The first launch of each PEP system is currently projected as the system qualification test, hence extensive pre and post launch support is being planned as indicated below.

	PEP No. 1	PEP No. 2
Pre-launch	6 weeks	5 weeks
Post-launch	4 weeks	3 weeks

Principal activities will be in support of the prime contractor plans and procedures at the launch facility that directly involve the solar arrays. Pre launch preparations may include receiving inspections at KSC, support during the PEP - Orbiter interface compatibility checks at the Cargo Integration Test Equipment (CITE) stand, and support during the Orbiter installation and checkout at the Orbiter Processing Facility (OPF). Support during the Vehicle Assembly Building (VAB) operations and at the launch pad are not planned since the PEP will not be operating. Support during the mission has not been defined or planned at this time. Following the first flight a complete inspection of the solar array panels and mechanical equipment is planned.

Tasks planned are:

- 100% cell inspection.
- Xenon flash electrical performance test on each module.
- Repair/refurbish any significant damage.
- Inspect/checkout structure and mechanisms.
- Inspect/checkout instrumentation.

These activities are planned to be accomplished at the launch facility, if required, using a modified version of the panel lay-up table. Maintenance and solar cell replacement will be performed at the inspection site as required.

4.6.3 Pre and Post Mission Support

The operational phase of the PEP life cycle is a new maintenance activity for solar array manufacturers. Electrical power systems using solar arrays have traditionally required minimal pre-mission servicing and the same is planned for PEP. Mechanical checks will be primarily functional. The extent of electrical checks will be determined as the number of mission increases. Early missions will have thorough post mission inspections and then as experience is gained the number and type of inspections after each mission should decrease. All maintenance and refurbishment activities are currently planned for the launch site facility.

5.0 MANUFACTURING FACILITIES PLAN

5.1 General Manufacturing Approach

This section describes TRW's plan for manufacturing the solar array blanket, containers and deployment hardware. Almost all of the component parts would be manufactured at TRW, Defense and Space Systems Group, located in Redondo Beach, California; the remainder would be obtained from outside vendors.

The general approach to the manufacturing and assembly of the PEP solar array is to make maximum use of existing tools, equipment and facilities that have been developed at TRW for other solar array systems. TRW has a highly automated solar module assembly and lay up facility. This equipment has taken significant capital and time to develop and debug, and has been successfully used in production of solar arrays for spacecraft programs such as FLTSATCOM, High Energy Astronomy Observatory (HEAO) and the Telemetry Data Relay Satellite System (TDRSS). Since the solar module components (solar cells, cover glass, interconnectors) and the assembly of these components represent major project costs, the continued use of the existing manufacturing processes represent significant cost savings to the PEP project.

Coordination between engineering and manufacturing groups was maintained to be certain that the unique features of the substrate and hinge designs are compatible with the automated equipment and solar cell stack laydown methods. Substrate, hinges and harness fabrications are also planned with existing TRW facilities capabilities and current plans are to preassemble these elements into a single assembly before the solar cell stacks are attached to the blanket.

This manufacturing plan is sub-divided into sections by the type of facility and manufacturing processes that are needed for particular components of the solar array. The facilities description are presented first and the manufacturing flow for the mechanical and electrical components are presented next. The plan is concluded with a summary of the solar cell procurement plan and support facilities and equipment items that are available for solar array fabrication.

5.2 Facilities Description

5.2.1 Mechanical Fabrication Facilities

The mechanical elements of the solar array wings are subdivided into two groups. The blanket elements include the substrates, hinges and harness. The housing assembly consists of the container, lid, latching mechanism, tensioning system, and guide wire system. All components, except the electric motors in the latch system will be fabricated and assembled in the TRW M3 Building as shown in Figure 20.

The substrates and hinge components will be cut to size and formed in the plastic shop of the building and assembled in a PEP identified assembly area. It is estimated that the forming and laminating equipment and secondary operations associated with this process will require 7000 square feet of existing floor space. The harness elements, with the exception of the conductors, would also be fabricated and pre-assembled in the plastic shop. About 60 square feet of floor space would be required, supplied with vacuum lines, electric power, water and drain. Attachment of the pre-assembled harnesses to the substrates would take place in the PEP substrate assembly area.

The container, lid, latches and other mechanical flight hardware will be fabricated as components in the sheetmetal and machine shops. These items will share facilities with hardware from other programs. Assembly of these items will take place either in the sheetmetal shop or the substrate assembly area. Tooling fabrication and GSE manufacturing would also be done in the M3 facility.

5.2.2 Solar Cell Assembly Facilities

All of TRW's solar cell lay-down and array assembly is located in one large clean room encompassing approximately 10,000 sq.ft. of 18,000 sq.ft.available floor space in Building M1 (Figure 21). The general area is environmentally controlled and can be maintained at a cleanliness level of Class 1,000,000. It is currently maintained as a Level II area in accordance with TRW Manufacturing Division Standard Practice 8.1.5, "Housekeeping Requirements for Controlled Areas". In general, these practices require limited access, smocks to be worn, no food, beverages or smoking, and provide a schedule for house-cleaning procedures. Details of the equipment in the facility are discussed in Section 5.3.2 on the solar module assembly and laydown.

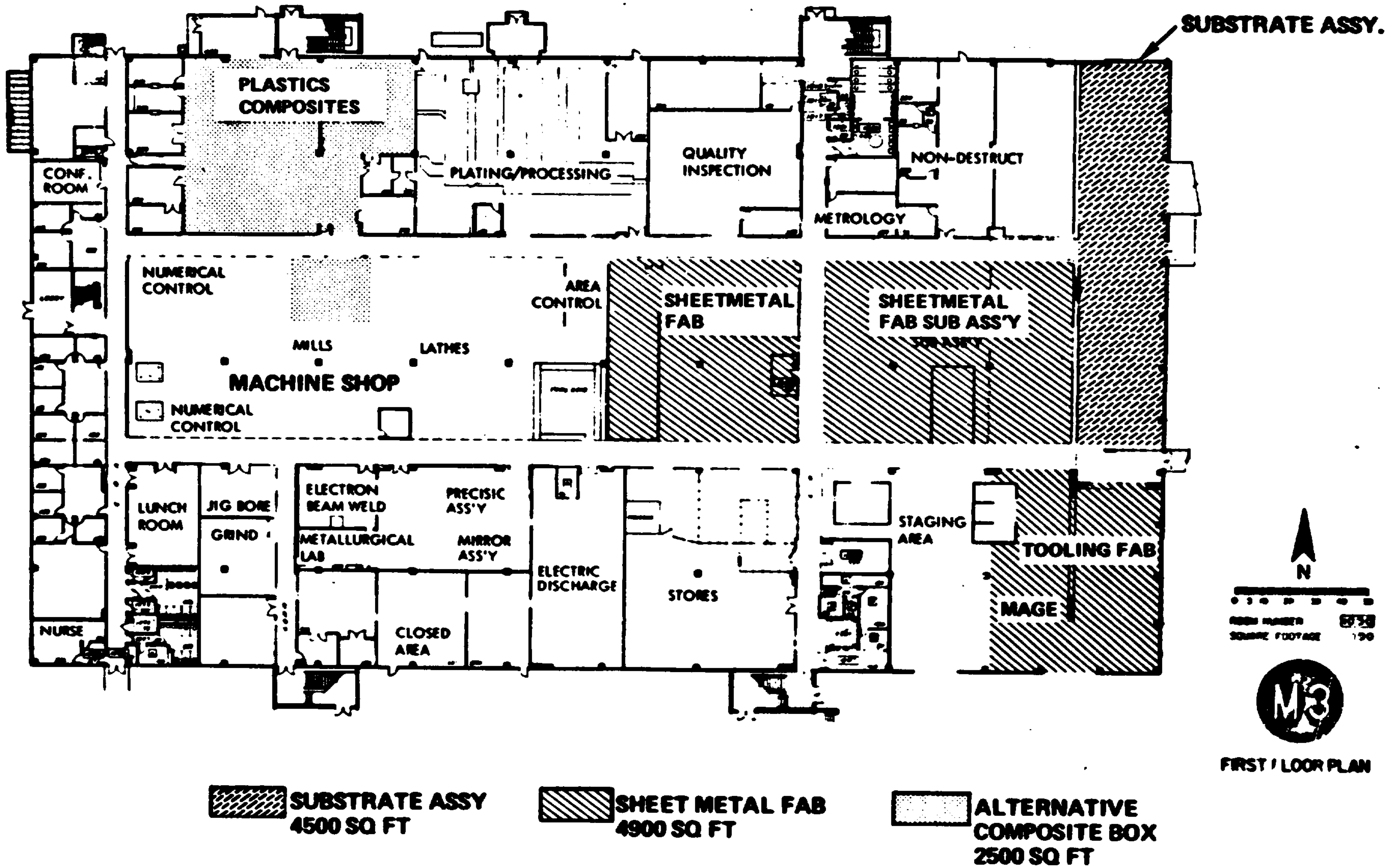


Figure 20. Solar Array Mechanical Fabrication Facility

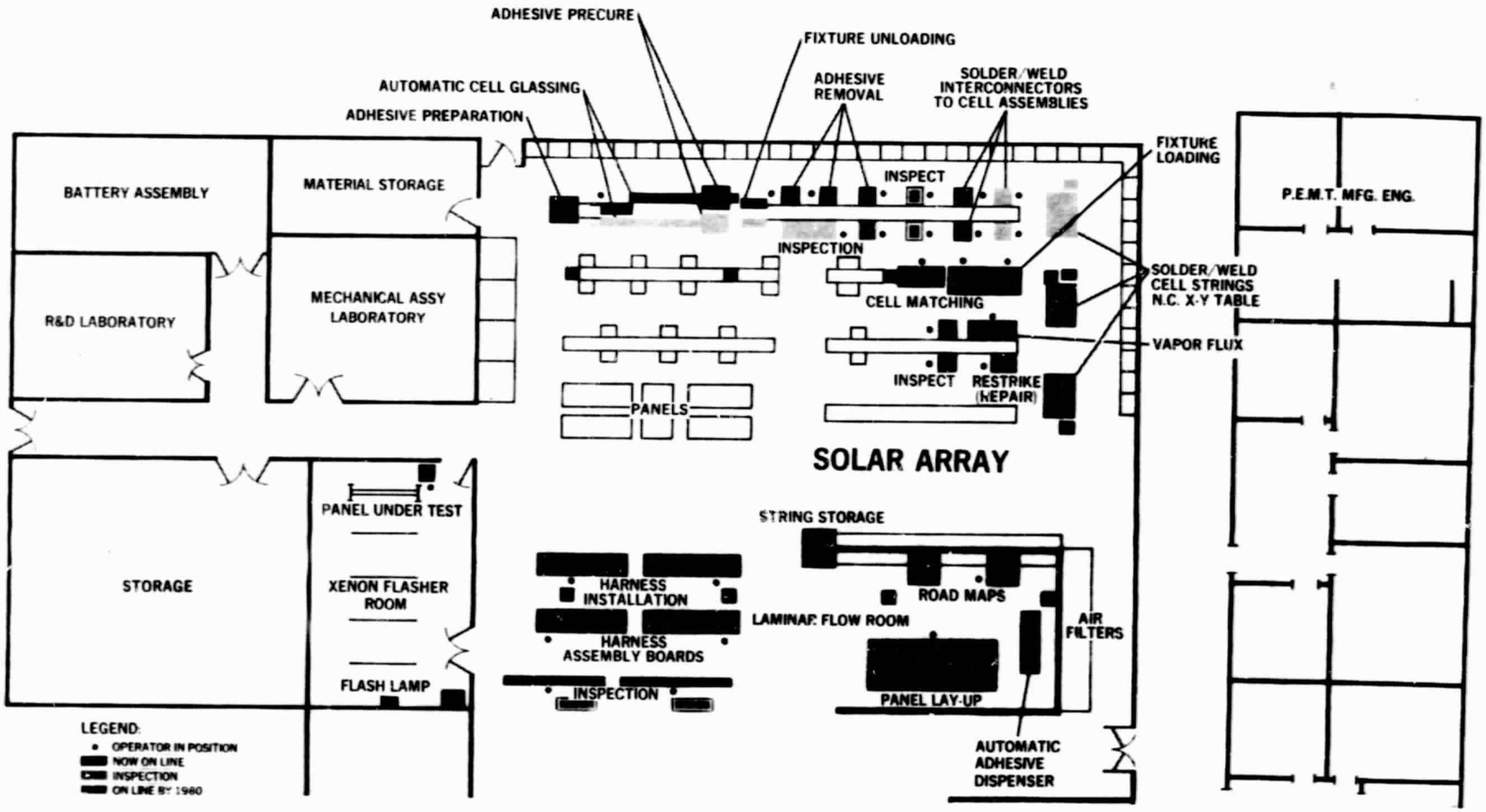


Figure 21. Solar Array Assembly and Test Facility

5.3 Manufacturing Flow

The overall manufacturing flow planned for the PEP solar array is presented in Figure 22. The harness, substrates and hinges will be fabricated and assembled on components that are then assembled into a blanket. Following deployment and alignment checks the solar cell stacks are attached and the electrical connections between the solar cells and harness are made. In parallel operations the containers and latch mechanisms are fabricated and assembled into the housing assembly. The last step is to install the blanket and tensioning mechanism in the housing assembly. Details of the process are discussed in the following sections of the manufacturing facility plan.

5.3.1 Mechanical Manufacturing

5.3.1.1 Blanket Container

The Array Blanket Container Assembly will be fabricated of aluminum honeycomb core with aluminum or graphite face sheets using conventional honeycomb layup and assembly methods in our Plastics Department. This department has the necessary equipment and expertise for extensive manufacturing of large and/or complex assemblies from these kinds of materials. The facility, is located at TRW. After fabrication, the container will be identified, inspected, packaged and put into stores for next assembly operation.

The container lid, latch mechanisms with motors, blanket tensioning mechanism and guide wires also will be fabricated by numerically-controlled and conventional machine shop equipment in the TRW machine shop. The resulting components will be identified, inspected, packaged and put into stores for the next assembly operation.

5.3.1.2 Substrate and Hinges

The Kapton Substrate Blanket Assembly is a new light weight, cost efficient, flat foldable blanket with appropriate stiffening and cushioning. The fabrication process, and major tooling and facilities required for the proposed substrate blanket and hinges are described in the following sections.

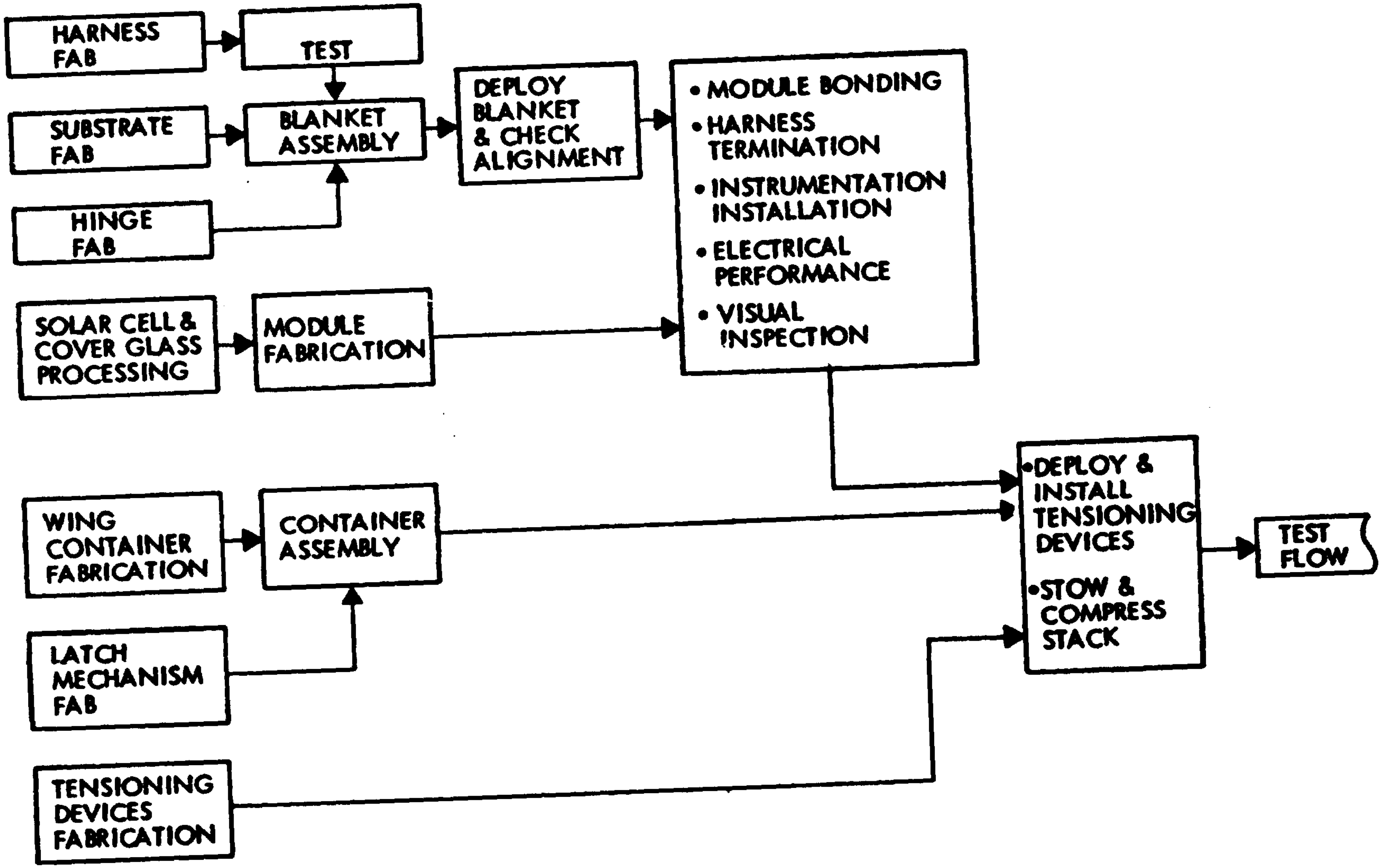


Figure 22. PEP Solar Array Fabrication Flow

5.3.1.2.1 Manufacturing - Tasks and Flow

The substrate blanket assembly flow from raw stock to the completed blanket assembly is shown in Figure 23. The Kapton and adhesive sheets are cut to size. Top and bottom panel substrates are formed to the rib-pattern needed for the substrate stiffening. In the following operation the two substrates are bonded together to form a panel and are trimmed to size. The hinge assemblies are fabricated in a parallel effort. They are attached and bonded to the length of the panels, joining one panel with the next to form the substrate blanket. Thereafter the substrate blanket assembly is dimensionally inspected in the unfolded and folded configuration.

At this time the two pre-assembled harnesses are installed and bonded to the outer edges of the substrate panels. After the blanket is inspected, again, in the folded and unfolded configuration, the entire assembly is ready for application of thermal paint, if required, to its rear side. Using the equipment planned, an estimated four (4) panels will be assembled per day.

The completed wing sub-assembly is cleaned, identified, inspected, packaged and stored for the next assembly.

5.3.1.2.2 Substrate Tooling

Special male-female forming tool sets will be needed to form the top substrate rib pattern and another set to form the bottom substrate rib pattern. Similarly, special mating sets of laminating platens will be needed to laminate the top and bottom substrate to each other to form a panel substrate.

Tooling sets and laminating platens will also be needed for forming the hinges and laminating them to panels. Another set of laminating platens will be needed to laminate the wiring harnesses to the panel ends.

5.3.1.3 Solar Array Harness

The foldable harness will be fabricated from polyimide (Kapton) film, using conventional stranded copper-clad aluminum wires laminated between the polyimide sheets (Figure 24). The harness will consist of two assemblies running parallel to the span of the solar array blanket and mounted at each outer edge. Hinges will be located in the harness to coincide with panel hinges.

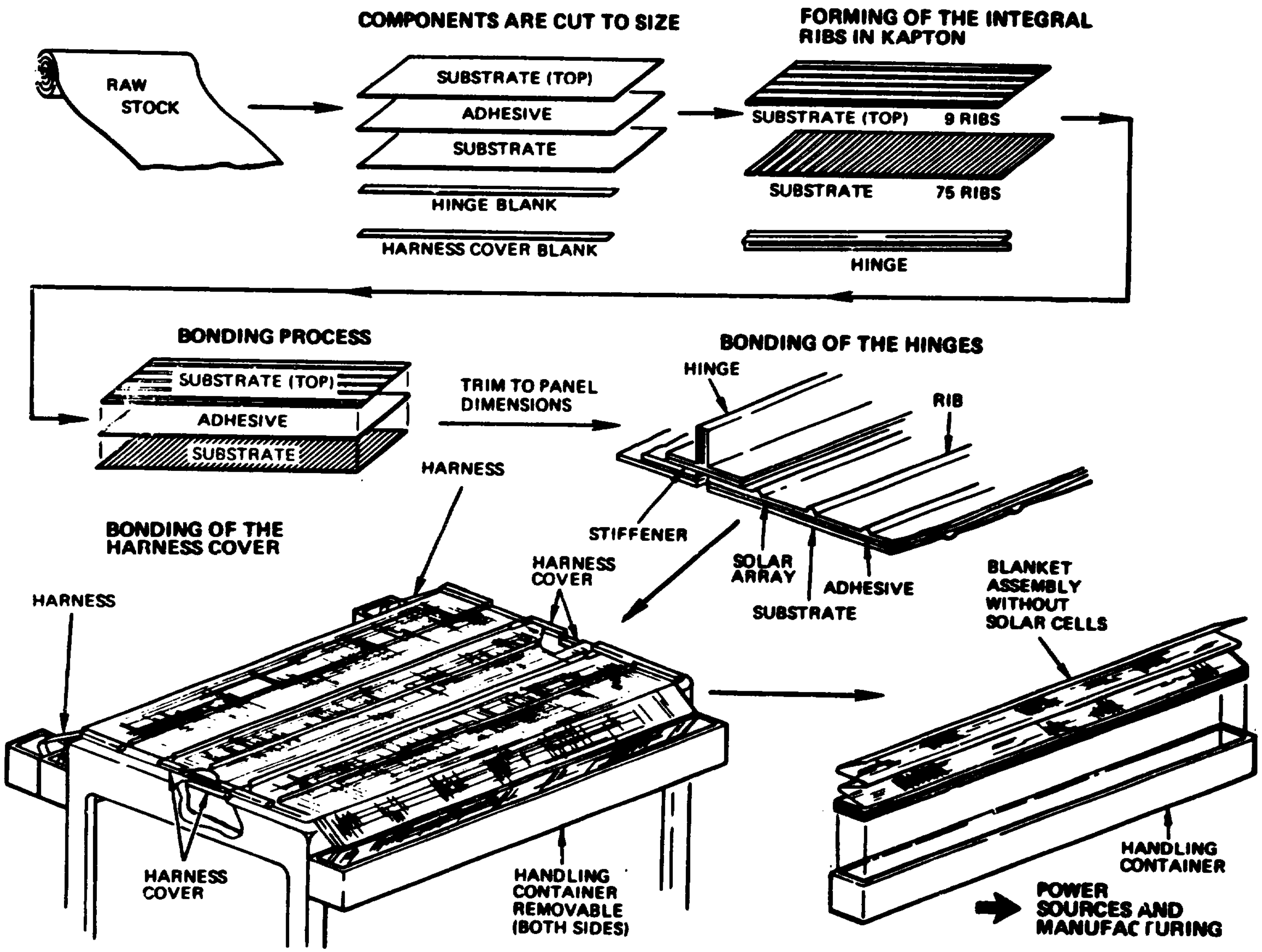
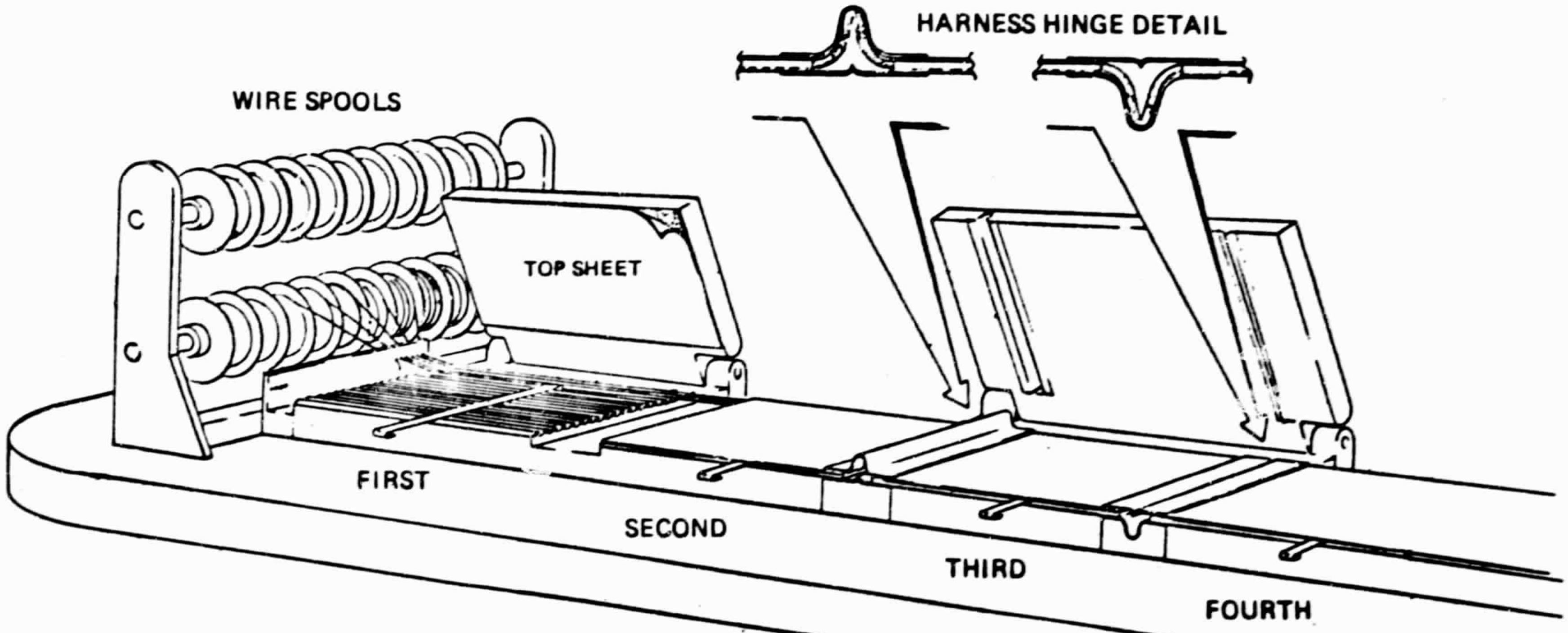


Figure 23. Fabrication of the Substrate Blanket



- STRANDED COPPER CLAD ALU. WIRE
- HARNESS WIRES ENCAPSULATED IN TWO PLIES OF ONE MIL KAPTON
- HARNESS RUNS BONDED TO ONE PLY OF SUBSTRATE
- HARNESS WIRES PREFOLDED AND EPOXYED AT HINGE LOCATIONS
- HARNESS TERMINATES AT CONNECTOR BOXES ON ARRAY CONTAINER

Figure 24. Harness Assembly Fixture

The harness will be fabricated, inspected, tested, identified, packaged, and stored for assembly with the solar array.

5.3.1.3.1 Harness Fabrication

From Kapton raw stock the various sheets are cut to size: bottom sheets, top sheets and hinge sheets, both top and bottom. The bottom sheets are formed into a corrugated shape. The assembly machine (shown in Figure 24) required placing a corrugated bottom sheet in place, then the harness wire is unrolled into the corrugations, and electrical connection is made with the panel-connecting ribbon. The top Kapton sheet is applied and laminated for the purpose of encapsulating wires and panel connecting ribbon, (which will extend towards the operator for right hand harness and away from operator for left hand harness). The first 15" x 6" section to be assembled is the one at the far outboard end of the array. Once this section is laminated, it is moved to the second station on the assembly machine, unreeling more harness wire and a second section is fabricated. The wires are formed into appropriate loops for the hinges, and then the Kapton hinge sheets are laminated between sections as shown in Figure 24. This process is repeated for all sections of one sub-harness, ending with the inboard termination section. As the sections are completed, they are inspected, tested and reworked if necessary. After quality acceptance, they are folded into an appropriate storage and transfer box.

Each section and hinge is visually inspected for bonding integrity and uniform lamination. Individual wires and ribbons are tested for electrical continuity, and the harness is tested for inter-conductor voltage isolation.

5.3.1.3.2 Harness Fabrication Equipment and Tooling

Equipment required includes a corrugating device for the Kapton sheets, similar in function to that used for the blanket substrate; an assembly fixture with heated platens and wire spools as shown in Figure 24; and suitable inspection equipment. A single work table 30" x 8' would suffice.

Tooling will consist of suitable forming platens for corrugation on the substrate sheets, tooling for forming the wire at the hinges and platens for laminating the Kapton portions of the hinges.

5.3.2 Solar Cell Module Assembly and Lay-up

This section describes the solar cell module assembly activities and their integration with the completed blanket substrate, including the foldable harness. Module assembly for two (alternate) solar cell sizes are discussed; the 2 x 4 cm (baseline) and the 5 x 5 cm.

5.3.2.1 Semi Automated Solar Array Assembly Line

The module assembly concept using 2 x 4 cm solar cells will be identical to that now used for on-going projects, using existing on-line semi-automatic and automated equipment. Figure 25 shows a typical assembly flow diagram for the PEP array, depicting the fourteen (14) major assembly stations and the four inspection points, (presently evaluated for semi-automation). This flow diagram is applicable for both cell sizes, the 2 x 4 cm and 5 x 5 cm solar cells, 0.02 cm (0.008 inch) thick. The present and near future capability will consist of individually operated processes with interim storage capability, rather than a conveyor belt system having all systems linked together. This approach provides the needed flexibility for meeting production schedules for various space solar array configurations. It also permits station repair and improvements without affecting the overall line operation. The on-line automatic and semi-automatic equipment in its present state is able to process more than 3200 solar cells, (2 x 4 cm in size) per 8 hour day.

Solar cell and cover glass magazines are employed to feed the automatic glassing line. The same type of magazine is planned for dispensing cells into the automatic interconnector attachment and solder/weld station. Flexible interconnected solar modules are handled with vacuum pick-up frames. With minor modification to the numerically controlled X-Y table, the module size can be scaled up to PEP requirements, fabricating one-half panels which would be handled without difficulty using pick-up frames. The equipment available for use in assembly of the PEP Solar Panel

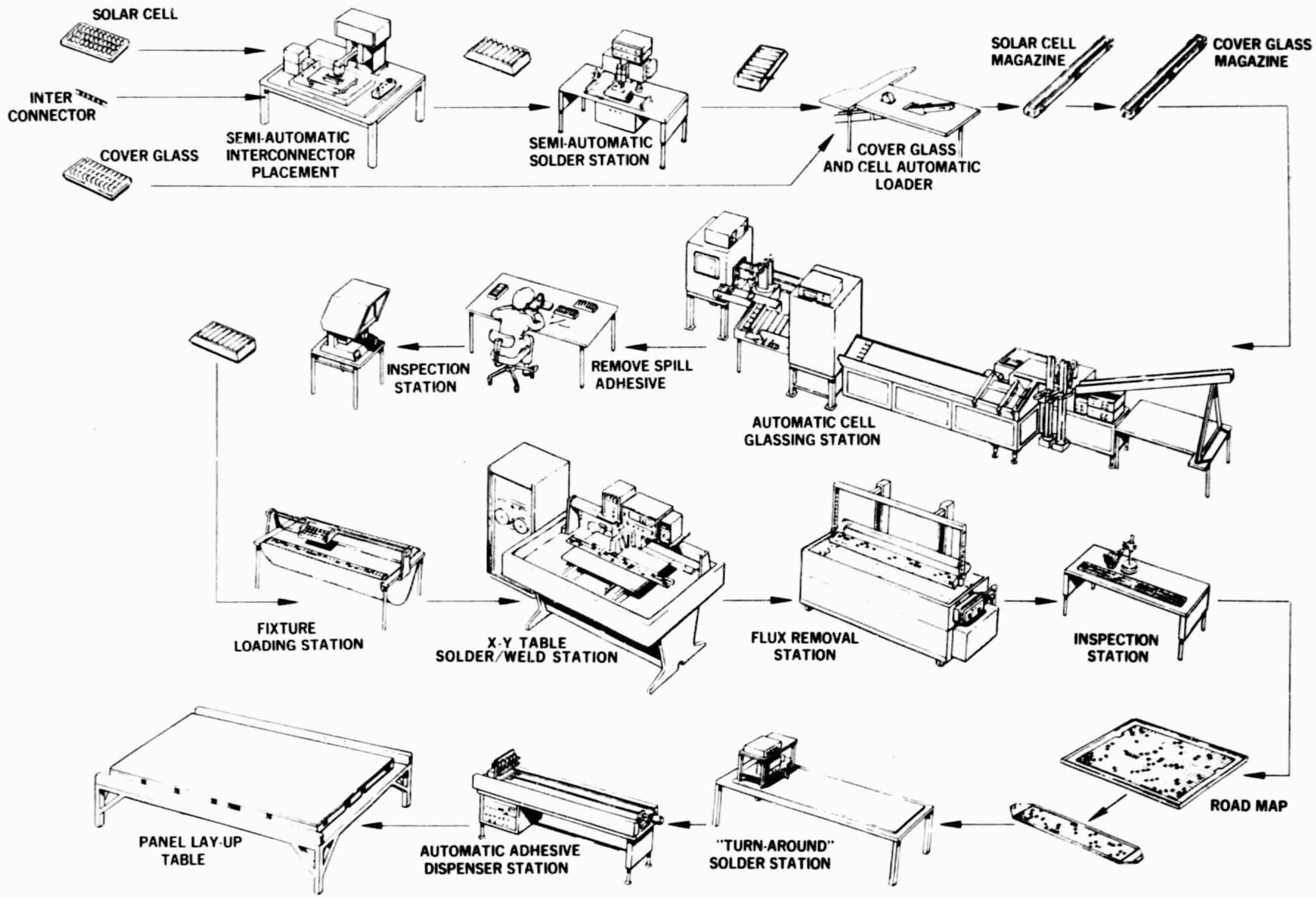


Figure 25. Semi Automated Solar Array Assembly Line

will meet the PEP delivery requirement. The equipment consists of the following:

- Solder reflow stations easily support the PEP requirements for the initial operation of attaching interconnectors to the bare cell (Figure 26).

- Automatic glassing operation (Figure 27) removes cells and glasses from pre-loaded magazines, places the cell in a positioning fixture, dispenses adhesive, assembles the cell/glass stack and transports the assemblies through a controlled temperature tunnel oven for an adhesive pre-cure.

- Numerically controlled X-Y positioning tables (Figure 28), equipped with dual solder reflow station (two simultaneous, individually controlled joints). These machines are utilized with appropriate fixtures, to automatically solder the cell/interconnector joints to produce the solar modules.

- Automatically sequenced cleaning operation which provides freon spray and vapor degreasing steps to remove flux while controlling total exposure time to prevent cover glass bond damage (Figure 29).

- Automatic adhesive dispensing machine (Figure 30), for application of adhesive to the backs of cells prior to lay-down on the panel substrate. This machine automatically positions itself above each cell and dispenses a controlled amount of adhesive. The adhesive dispensing machine is located with a lay-up table in a large laminar flow area to provide contamination control during lay-up operations.

- Large area pulsed Xenon Solar Simulator (Figure 31), at one solar constant within $\pm$ 2 percent uniformity. An attached data console provides an instantaneous printout of the panels performance. Light conditions as sensed by a standard solar cell, traceable to a NASA/JPL ballon flown standard solar cell.

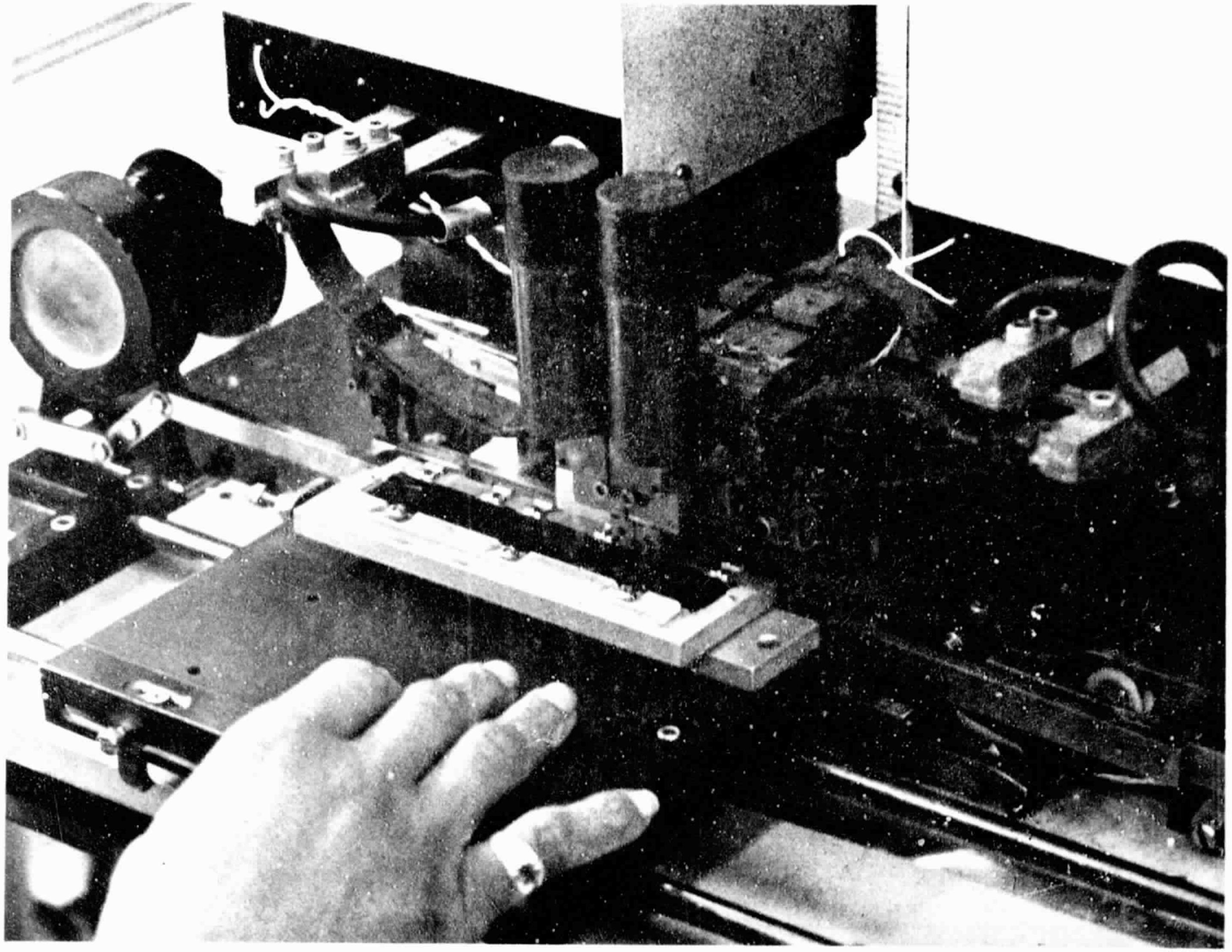


Figure 26. Semi-Automatic Interconnection

Figure 27. Automated Glassing Line

Figure 28. Numerically Controlled X-Y Solder Station

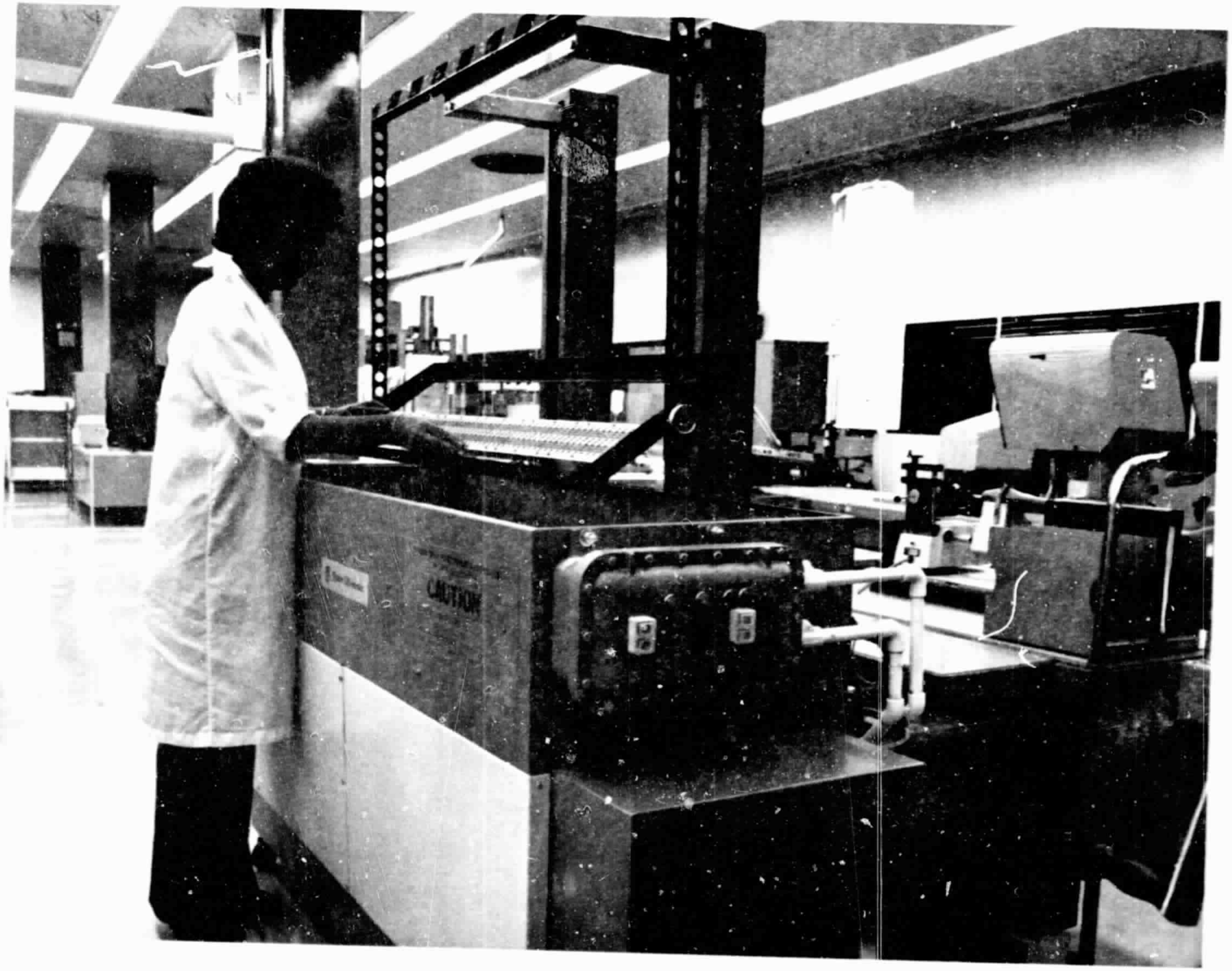


Figure 29. Flux Removal Station

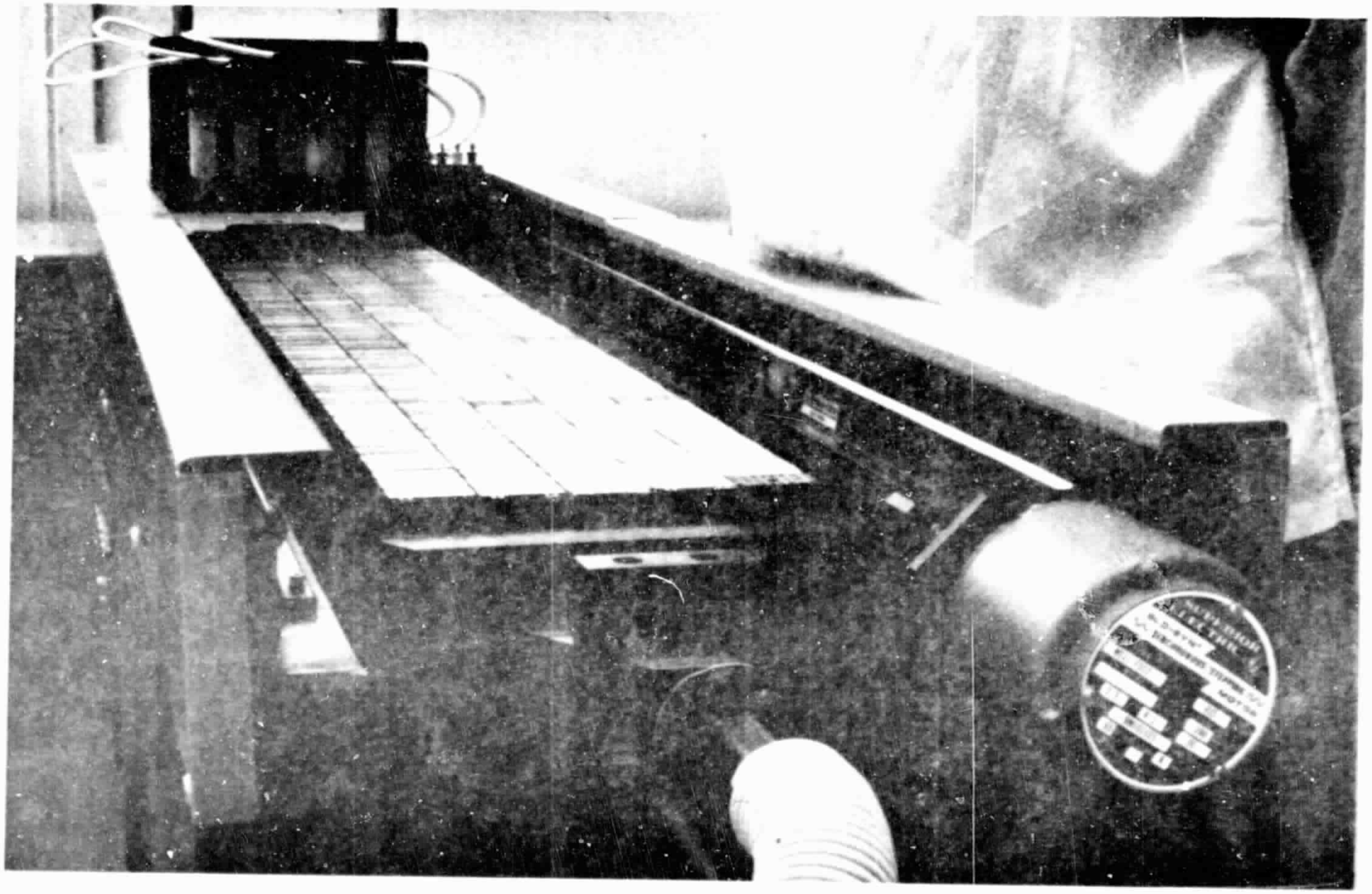


Figure 30. Automatic Adhesive Dispenser

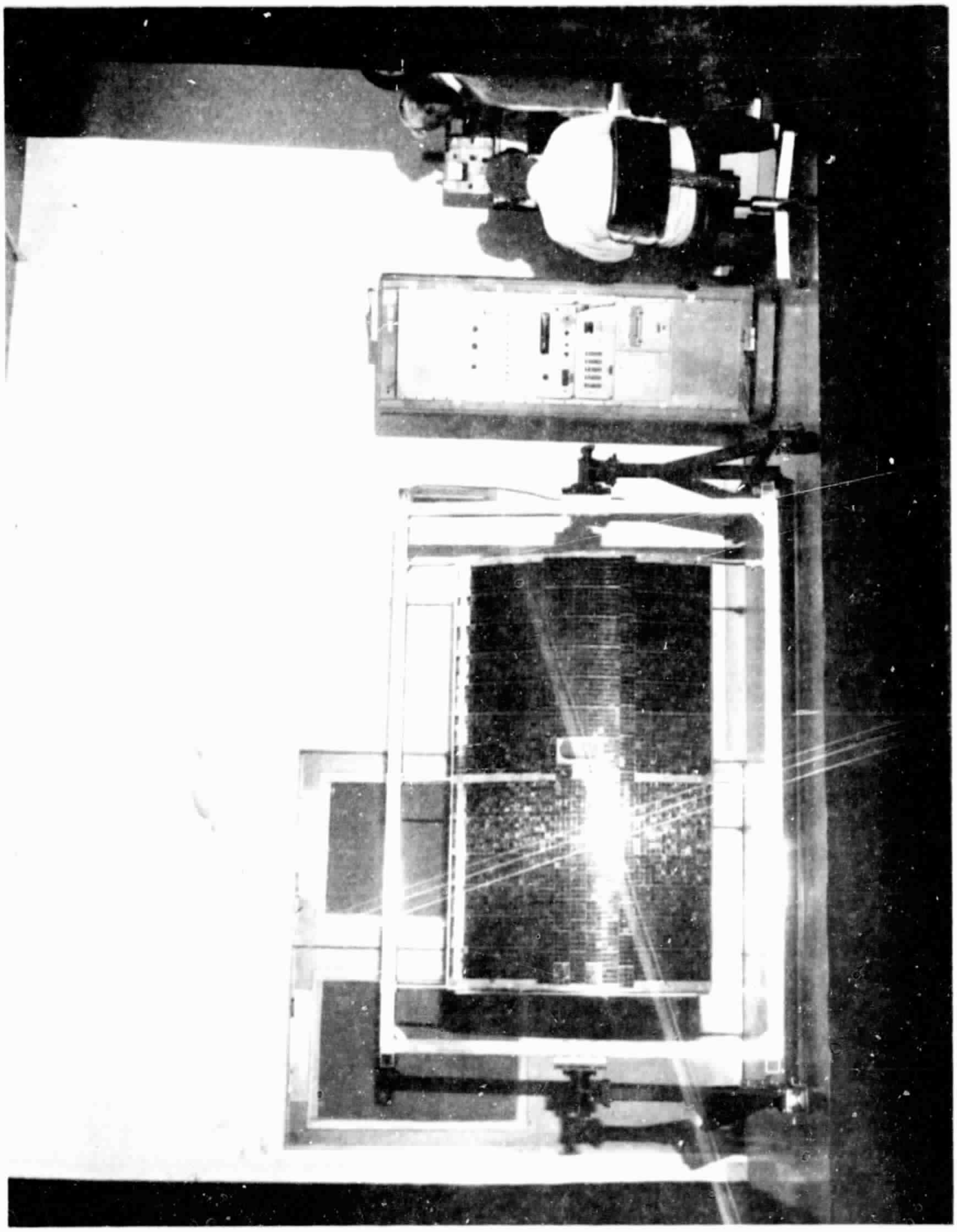


Figure 31. Large Area Pulsed Solar Simulator

5.3.2.2 Future Automated Assembly Line

TRW has, over the last ten years, continuously improved its assembly process, primarily to improve reliability and to reduce the assembly cost. Company funds are made available every year for this purpose. Many minor improvements leading to improved work-flow and reduction in time-motion are currently being implemented, together with several major improvements in such areas as the Automatic Interconnector Placement and Adhesive Removal station; Solder/Weld operation, the Fixture Loading (by cell grade) operation and various inspection stations. An illustration of the improved solar array assembly line is presented in Figure 32. Projected capability in the 1981 time period with these improvements is greater than 4000 cells per 8 hour shift.

5.3.3 Solar Cell Procurement

The present PEP solar array design requires 489,600 solar cells, 2 x 4 cm in size. This translates into a solar cell production rate of 2,400 cells/day or 12,000 cells/week (for two PEP systems). Even though a single solar cell manufacturers production rate would be able to accommodate such rates per week, TRW recommends procuring cells from two vendors in order to guarantee cell availability should one vendor fall behind in delivery. High efficiency flight proven solar cells will be purchased to TRW's specification. Quality verification of the integrity of solar cells will be performed at supplier by TRW Source Inspection. Conformance to specifications and process requirements will be verified at source by TRW Quality Assurance representatives. The electrical cell integrity will be verified and witnessed by a TRW Quality Representative at the supplier facility.

The solar cell specification covers the following requirements for space flight applications:

1. Design & construction
   - 1.1 Uniformity of product
   - 1.2 Cell material
   - 1.3 Anti-reflective coating
   - 1.4 Cell contacts and gridlines
   - 1.5 Solar cell junction area

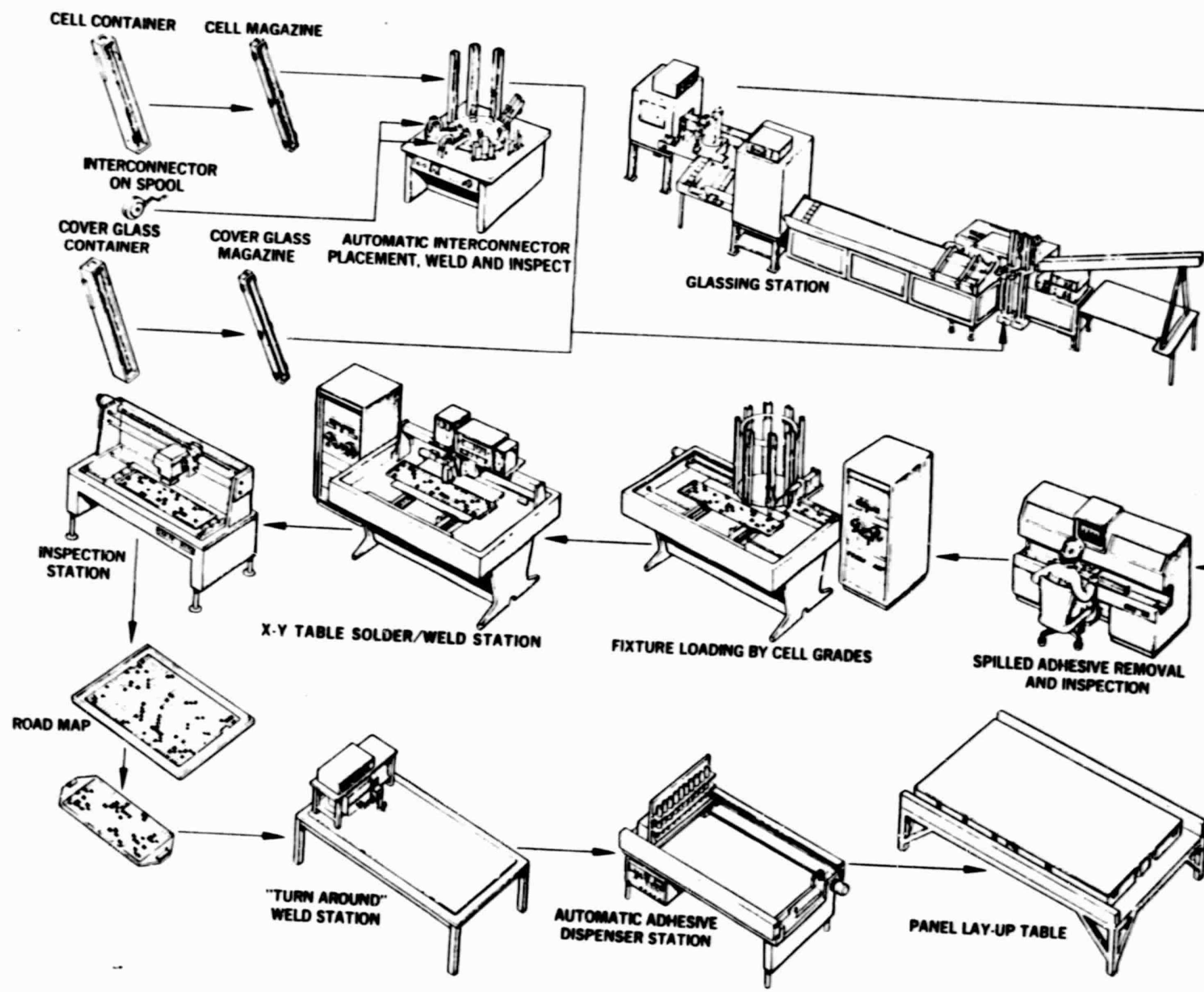


Figure 32. Future Automated Solar Array Assembly Line

2. Performance
   2.1 Electrical output
   2.2 Electrical output (after cover installed)
   2.3 Electrical output (after charged particle radiation)
   2.4 Cell contact integrity, (contact pull testing before and after humidity and temperature exposure).
3. Dimensions and Weight
4. Color and Finish
   4.1 Color and appearance
   4.2 Mechanical imperfections

5.3.4 Program Related Support Facilities and Equipment

5.3.4.1 Solar Engineering Laboratory

The Solar Array Manufacturing and Test activities are directly supported by the adjoining Solar Engineering laboratory. This laboratory operates under the direction and management of the Solar Engineering Group. Its primary responsibilities are maintenance of standard solar cells, monitoring of solar simulator performance, and solar cell characterization and environmental testing. Facilities of this laboratory include:

- o Large area pulsed Xenon Solar Simultor, 7 x 7 foot area at one solar constant within ± 2 percent uniformity.
- o Spectrolab X-25 solar simulator, 7 x 14 inch area at one closely filtered AMO solar constant within ± 2 percent uniformity.
- o OCLI Module 31 solar simulator, 1 x 1 inch area at one closely filtered AMO solar constant within ± 2 percent uniformity.
- o Set of 18 optical narrow band pass filter in 0.33 to 1.13 micron wavelength range for solar simulator spectral calibration.
- o Two temperature cycling chambers modified for preprogrammed automatic continuous operation from -190° to + 150° C.

- Thermal vacuum chamber designed for accelerated temperature cycling to low temperature in hard vacuum.
- Thermal shock apparatus for alternately immersing test samples in gaseous LN_2 and exposing them to infrared heating. Automatic operation with adjustable cycle and dwell times.
- Roll/Fold apparatus for testing roll-up and fold-up solar array samples. Automatically operating with number-of-cycle counter and automatic stop when specimen open circuits. Easily changeable roll diameter, tension weights, and stroke time. Pneumatically actuated with 8-inch stroke.
- Pulsed dark forward V-I characteristics measuring equipment.
- Solar cell interconnector flexing apparatus. Adjustable stroke simulates varying intercell spacings due to temperature cycling or mechanical effects.
- Interconnector open-failure detector.

5.3.4.2 Materials and Processes Support

The Materials and Processes Department of the Manufacturing Division has equipment and personnel to perform material property evaluation and testing in four basic areas: Microscopy, Mechanical Testing, Analytical Chemistry, and Electrical Property Evaluation.

5.3.4.3 Environmental Test Facility

To support its many spacecraft related test programs, TRW has developed an outstanding dynamics test capability. This capability covers a broad spectrum of engineering experience and facilities to cope with practically any conceivable dynamic test requirements. Available are high-force multiple shaker arrays for testing massive systems, numerous other shakers for components and subsystems, a 15,000 cubic foot acoustic chamber, high intensity shock machines, an automated modal survey system, and associated data acquisition and reduction facilities.

6.0 COST/RISK ASSESSMENT

6.1 Cost Analysis

The data presented in this section represents estimated costs to design, develop, manufacture, test and deliver solar arrays for two complete PEP systems. This includes four solar array flight wings plus an engineering development model. The ground rules and assumptions that were used in developing the costs are summarized in Section 6.1.1 and the work break-down structure is discussed in Section 6.1.2. The cost data is summarized in Section 6.1.3.

6.1.1 Costing Ground Rules and Assumptions

The ROM type costing that has been developed is based on the configuration presented in Section 3 of this document using drawings and sketches from the conceptual design phase. Since drawings on all parts were not available,the estimates to a certain extent rely on similarity to past projects where drawing lists can be compared. Where purchased parts are involved vendor quotes have been obtained. For the solar cells and cover glasses, unit cost estimates were provided by several manufacturers who were informed of the quantities and the specific design features required.

The cost estimates were developed for the baseline program schedule discussed in Section 4.0 of this document. This assumes an ATP of 1 October 1980, completion of design by February 1982 and delivery of the first two wings by January 1983 and the final pair by August of 1983. Also included were costs to support the prime contractor when the flight units are initially delivered and when the first flight of each PEP system is made. All cost data is forward priced, meaning that estimated labor rates and material costs over the time period of late 1980 thru 1983 were used, with the exception of solar cells and cover glasses. Delivery of these items from the vendors will not be completed until late 1982. All cost figures are fully burdened but do not include fee or cost of money.

Certain important assumptions were made regarding solar cells and cover glasses. The first is that the development and qualification of the selected cell has been completed or sufficiently completed to be assured that the PEP

requirements will be met. This applies to the large cell as well as the baseline 2 x 4 cm cell. The second assumption is that the vendor or vendors will be able to deliver cells and covers at a rate of 12,000 per week for the smaller size and 3500 per week for the large size. These appear to be realistic levels based on discussions with the manufacturers and considering other demands on their production capabilities. The final assumption is the solar cells and cover glass attrition rates will not exceed the following levels.

Solar Cell Sizes	Attrition Rates	
	Cells	Covers
2.22 x 3.96 cm	10%	13%
5.70 x 5.30 cm	15%	18%

The percentages are the quantities required over the specific number of flight units needed plus an allowance for engineering model tests, life cycle tests and component acceptance tests. These assumed rates are based on experience in handling the smaller cell with the semi-automated assembly line and extrapolating that experience to the large cell handling. The data does not include attrition at the solar cell vendor facility which is already reflected in the unit price.

6.1.2 Work Breakdown Structure

The work breakdown structure for the ROM cost exercise is shown in Figure 33. The subtier activities are also listed. Key elements included in the cost data are as follows:

- Baseline Design - 2.22 x 3.96 cm cells/cover glass, 1200 cells/panel, 102 panels/wing, 2 wings/system. Container/spreader bar/tension system/guide wires and latching mechanisms for each wing.
- Alternate Design - 5.3 x 5.7 cm cells/cover glass, 360 cells/panel, 100 panels/wing, 2 wings/system. Other elements same as baseline design.

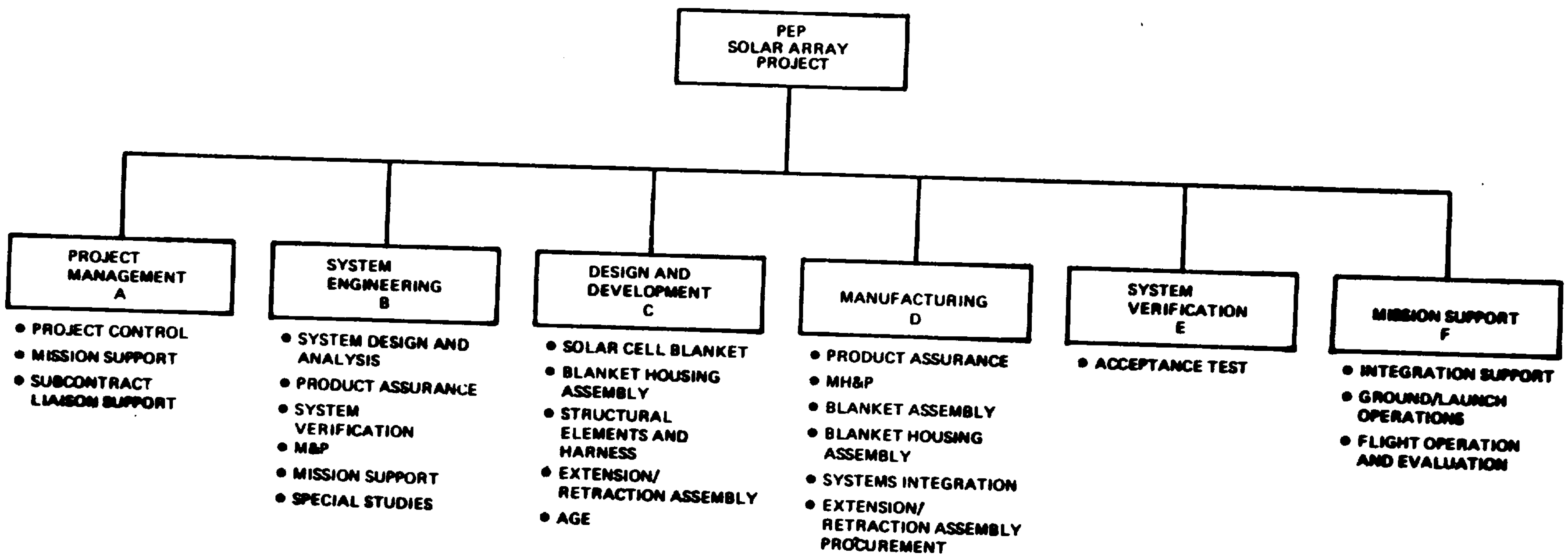


Figure 33. Work Breakdown Structure for Cost Analysis

- Two flight systems plus one development model wing. Development model includes two panels with cells, 100 panels with dummy cells and all other elements necessary for a complete wing.
- Substrate fabrication using hot forming techniques with two shifts per day.
- Development/Qualification/Acceptance testing as outlined in Program Plan.
- Protoflight concept for first production wing.
- Mission support includes one month before and after first flight of each PEP system.
- Spares includes 10 panels with solar cells.

Data was collected for both recurring and non recurring categories in all WBS elements. Options included the baseline configuration, the alternate configuration, a graphite epoxy housing assembly, and mast/canister units. For the first two options complete program costs were compiled and only incremental (delta) costs are presented for the latter two. The mast/canister devices, as stated early, were not a part of the solar arrays for this study, however they may be included in the follow-on phase. The delta costs for the masts are based primarily on vendor quotation plus the added effort for handling and blanket functional testing using the mast and canister.

6.1.3 Cost Data Summary

The ROM cost data are summarized in Figures 34 and 35. The total cost for the baseline design is estimated at $35,240,000 with approximately 37% as non recurring costs. The alternate design using the large solar cells is $31,538,000 with approximately 42% as non recurring. The savings of 3.7 million dollars is all recurring costs related to the savings in solar cells and the labor associated with the processing of fewer cells and cover glasses. It should be noted however that the savings is based on a solar cell that is not yet developed and hence the estimated costs per cell may change significantly once the cell is in production.

OPTION	$000 NON RECURRING COSTS	$000 RECURRING COSTS	$000 TOTAL
BASELINE DESIGN	13,065	22,175	35,240
ALTERNATE DESIGN	13,118	18,420	31,538
DELTA COST ITEMS			
MAST/CANISTER (4 FLT UNITS)			1,095
GRAPHITE CONTAINERS (5 UNITS)			314

Figure 34. Cost Summary Data

WBS ITEM		$000
A.	PROJECT MANAGEMENT	2,336
B.	SYSTEM ENGINEERING	3,831
C.	DESIGN AND DEVELOPMENT	8,250
D.	MANUFACTURING	19,700
E.	SYSTEM VERIFICATION	599
F.	MISSION SUPPORT	524
	TOTAL	35,240

Figure 35. Cost Breakdown for Baseline Configuration

The delta costs for the 4 mast/canister is approximately 1.1 million, and a little more than 0.3 million addition if the graphite containers are used in lieu of the aluminum ones that are in the baseline design. A breakdown of the costs for the baseline design is presented in Figure 35. It shows that approximately 56% is in the manufacturing element which is to be expected considering the solar cells and cover glasses make up a large part of the total material costs and that a relatively large number of identical units (i.e., blanket panels) are being produced. Solar array verification and mission support are approximately 3% of the total which is consistent with past experience that shows relatively minor testing and support activities are required for solar arrays.

6.2 Risk Assessment

An assessment was made of the risk associated with the PEP Solar Array designs. The assessment was made in terms of high, medium and low risk for major elements of the baseline and the alternate designs. The results are presented in Figure 36. The basis for the assigned risk category is subjective and is due to the following rationale.

- Solar cells and interconnects.

  The solar cells for the baseline configuration are a 2 x 4 cm size and derived from a P^+ cell design that is flight proven. Therefore the solar cell manufacturers are working with a standard size cell with design features that have been fabricated, qualified and flown in space. The same rationale applies to the TRW interconnector selected and the solder techniques used in attaching the interconnectors to the solar cells. Hence the basis for designating the low risk category is that it is a flight proven design that is familiar to the manufacturers. In the alternate design the large 5 x 5 cm solar cell is not a proven design and has not been flight proven. Recognizing the development effort NASA will be doing in the near future is the basis for designating the large cells a medium risk item.

PARAMETER	RISK		
	LOW	MEDIUM	HIGH
BASELINE DESIGN			
SOLAR CELLS AND INTERCONNECTS	X		
SUBSTRATE		X	
LATCH/TENSION MECHANICAL FEATURES	X		
FABRICATION AND ASSEMBLY	X		
SCHEDULE AND DELIVERY	X		
ALTERNATE DESIGN			
SOLAR CELLS AND INTERCONNECTS		X	
SUBSTRATE		X	
LATCH/TENSION MECHANICAL FEATURES	X		
FABRICATION AND ASSEMBLY	X		
SCHEDULE AND DELIVERY		X	

Figure 36. PEP Solar Array Design Risk Assessment

- o Substrate

  The use of foldable, lightweight flexible substrates in large solar arrays have not been used in the past and therefore is an unproven design. The Kapton material in the substrate is flight proven and has been demonstrated to have good radiation resistance properties. Therefore the substrate feature is designated as a medium risk item. Since both the baseline and alternate solar array designs are near identical in this item, the risk assignment is the same.

- o Latch/Tension Mechanical Features

  The primary mechanical features of each design are the same and do not involve any unique concepts even though the application may be new. Since standard materials are planned to be used in the mechanical design the risk is considered to be low.

- o Fabrication and Assembly

  The principal concern in the solar array fabrication and assembly area is associated with the solar cell and cover glass processing and assembly. This activity is highly automated in the TRW manufacturing facility and for the most part is relatively independent of the size of the solar cells. Since this area and the other features of the design are very conventional and familar to the shop personnel this item was also considered to be low risk.

- o Schedule and Delivery

  The baseline design using the conventional size solar cells is considered to be low risk because the quantities and delivery rate and cells coupled with the overall slack in the schedule appears to be well within the production capacity of the solar cell manufacturers. The alternate design however uses a large solar cell that has not been produced in quantities in the past and is inherently more fragile than the smaller

cell. For this reason it is designated as a medium risk item.

It is acknowledged that at least a year of time will elapse before the hardware program will begin. During this time period, NASA/JSC will be funding the solar cell manufacturers to develop and qualify the large solar cells. If this development proceeds successfully then the medium risk designations in Figure 36 could be reduced.

7.0 REFERENCES

1. TRW Document 35515-6001-RU-00, "PEP Solar Array Definition Study, Final Technical Report," 15 November 1979

2. McDonnell Douglas Document 52949, "PEP Technical Review," 17 Many 1979